JOINT HIGHWAY RESEARCH PROJECT

FHWA/IN/JHRP-88/1

Interim Report

PRIORITY ASSESSMENT OF ROUTINE MAINTENANCE NEEDS AND OPTIMAL PROGRAMMING

Tien F. Fwa
John D. N. Riverson
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PRIORITY ASSESSMENT OF ROUTINE MAINTENANCE NEEDS AND OPTIMAL PROGRAMMING

EXECUTIVE SUMMARY

Interim Report

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Project No.: C-36-63K

File No.: 9-7-11

Prepared as Part of an Investigation

Conducted by

Joint Highway Research Project
Engineering Experiment Station
Purdue University

in cooperation with the

Indiana Department of Highways

and the

U.S. Department of Transportation
Federal Highway Administration

Purdue University
West Lafayette, IN 47907
January 28, 1988
Revised June 6, 1988

PRIORITY ASSESSMENT OF ROUTINE MAINTENANCE NEEDS AND OPTIMAL PROGRAMMING

EXECUTIVE SUMMARY

TO: H. L. Michael, Director
Joint Highway Research Project

FROM: Kumares C. Sinha, Research Engineer
Joint Highway Research Project

January 28, 1988
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Attached is the third Interim Report on the HPR Part II Study entitled, "Assessment of Routine Maintenance Needs and Optimal Use of Maintenance Funds". This interim report covers the Tasks E and F dealing with model development and testing. This phase was conducted by Tien-Fang Fwa and John D. N. Riverson under the direction of Kumares C. Sinha.

This report is forwarded for review, comment and acceptance by the IDOH and FHWA as partial fulfillment of the objectives of the research.

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This report presents the findings of the research work that was undertaken to determine the priorities of maintenance work as perceived by unit foremen as well as to develop an optimization routine that can be used to develop periodic work schedules. The model uses an integer programming formulation for application at the network level. The model parameters were developed on the basis of a survey of various subdistrict personnel in Indiana.

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Introduction

The Indiana Department of Highways (IDOH) has initiated several Joint Highway Research Project studies at Purdue University on routine maintenance in the past. The present study is the last phase of the HPR research project entitled "Assessment of Routine Maintenance Needs and Optimal Use of Routine Maintenance Funds" [1]. Results of the earlier phases of the research study have been presented by Montenegro and Sinha [2] and Feighan, et al. [3]. Montenegro and Sinha recommended a procedure for condition assessment and provided work quantity standards for estimating workloads for various routine maintenance activities. Feighan, et al. provided estimates of expected lives and unit costs of various routine maintenance activities.

The purpose of this phase of the research was to develop an optimization programming model for scheduling routine maintenance activities at network level within the framework of the existing maintenance management system of Indiana. The fulfillment of this objective required, in addition to the data and results obtained from the two earlier studies mentioned above, information on (a) priority ratings of various routine maintenance activities, and (b) the influence of rehabilitation schedule on routine maintenance scheduling. This report presents the results of a survey conducted specifically to acquire information in these two aspects, and a detailed description of the development and application of the proposed optimization model.

Priority Ratings of Routine Maintenance Activities

The priority ratings of routine maintenance activities surveyed were developed from a survey of IDOH field personnel (District and/or Field

Engineers, Superintendents and Unit Foremen). The relative priority ratings were also determined for pavement distresses on Interstates as well as High Volume (> 400 vpd) and Low Volume (Less than 400 vpd) Other State Highways. The fourteen IDOH routine maintenance activities were as follows: 201, 202, 203, 204, 205, 206, 207, 208, 210, 211, 212, 213, 231 and 234.

The survey was divided into two parts. Part one dealt with assigning priority scores to individual routine maintenance activities in accordance with their relative importance in preserving highway pavement conditions at a desired level. In part two, priority scores were assigned to different pavement condition levels for various highway classes, by their relative urgency of need for maintenance work. Dividing the contributing factors into two parts as described successfully reduced the number of entries in each part to a size manageable for ranking purpose.

The priority scores in each part were arrived at by following a two-stage procedure. Raters were asked to rank the entries in each part first before proceeding to priority score assignment. This two-stage procedure was well received by the raters as it greatly facilitated the priority score assignment process.

The final priority ratings of routine maintenance activities by highway class and pavement condition were computed by combining the priority scores of the two parts. These priority ratings could then be entered as routine maintenance weighting coefficients in the proposed optimization model.

Rehabilitation Constraints

A concept of interference period was introduced in this study to account for the influence of rehabilitation projects on routine maintenance programming. An interference period was defined as the time period during which a given routine maintenance activity would be suspended, due solely to the scheduling of a rehabilitation work. The length of interference period varies from maintenance activity to maintenance activity. It is also dependent on the importance of the highway section concerned, as well as the severity of the pavement distress that needs to be corrected.

The average interference periods for various maintenance activities, by highway class and distress severity, were computed from survey results for both the North and South regions of Indiana. These data enabled the rehabilitation constraints to be explicitly formulated in the optimization programming model developed in this study.

The Optimization Model for Routine Maintenance Programming

An integer programming model [4] was developed to arrive at an optimal combination of routine maintenance activities for achieving the goal of preserving highway systems under a given set of constraints. The constraints considered included maintenance need requirements, budget, manpower, material and equipment availability, and pavement rehabilitation schedule.

Most of the necessary input data for the model operation are already

available from the IDOH maintenance management system. The value and usefulness of the output information depend much on the accuracy and completeness of the acquired data. The report discusses the types and forms of data needed and the ways in which such data are acquired and processed in Indiana. A numerical example illustrates the procedure of data computation involved in a routine maintenance programming analysis using the proposed model.

Application of the Model

The proposed programming procedure is expected to enhance the efficiency and effectiveness of the existing maintenance management system in Indiana. It is considered appropriate for application at subdistrict levels in Indiana. The following are potential impacts on the maintenance management system in Indiana.

1. The current bi-monthly selection of routine maintenance activities can be enhanced by the proposed programming procedure without changes in the existing management structure. A program can be formulated for a more effective and economical use of resources.

2. Non-uniform and inconsistent decision-making, which may result from the present routine maintenance programming procedure, could be eliminated. Uniformity and consistency across the state at the subdistrict level can greatly help planning, monitoring and evaluation of routine maintenance performance on a statewide basis.

3. The model can be easily expanded and modified for use at other network levels. Also, program periods other than the two-week period currently

used in Indiana can be analyzed to provide longer-term information which may be useful for planning purposes.

4. Shortfalls and surpluses of resources can be analyzed. The possible benefits of re-allocating resources can be investigated by performing parameter sensitivity analyses. These analyses are useful because certain parameters might have been set as a result of managerial policy decisions, and these decisions could be reviewed after examining their consequences on what can be achieved. The amount of resources to be made available to a given activity may be adjusted to achieve better results. For instance, the number of temporary laborers to be hired over a given period of the year could be determined by such analyses.

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Interim Report

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INTERIM REPORT

TO:	H. L. Michael, Director Joint Highway Research Project	January 28, 1988 Revised June 6, 1988 Project No: C-36-63K
FROM:	Kumares C. Sinha, Research Engineer Joint Highway Research Project	File: 9-7-11

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CHAPTER 1

INTRODUCTION

An area of major concern for most highway agencies today is routine maintenance. Interest in pavement maintenance management has grown rapidly in the last decade owing because routine maintenance has become a major consumer of limited highway funds, and that timing, frequency, extent and type of routine maintenance work have a significant impact on the performance of highway pavements [1,2]. One important function of a pavement maintenance management system is therefore to provide highway maintenance managers an effective tool to formulate a good routine maintenance program to maintain and preserve the road network under their charge at or above a desired standard.

The Indiana Department of Highways (IDOH) has initiated several Joint Highway Research Program studies at Purdue University on routine maintenance in the past [3,4]. The present study is the last phase of the 1984 HPR II Proposal on the "Assessment of Routine Maintenance Needs and Optimal Use of Routine Maintenance Funds" [5]. Results of the earlier phases of the research study have been presented by Montenegro and Sinha [6] and Feighan, et al. [7]. Montenegro and Sinha recommended a procedure for condition assessment and provided work quantity standards for estimating workloads for various routine maintenance activities. Feighan, et al. provided estimates of expected lives and unit costs of various routine maintenance activities based on recommendations by Montenegro and Sinha.

The purpose of this phase of the research is to develop an optimization model for programming routine maintenance activities at network level within

the framework of the existing maintenance management system of Indiana. To fulfill the above objective, a survey of various subdistrict highway personnel in Indiana was conducted to assess routine maintenance needs priority and ranking. In addition, the influence of the resurfacing schedule on various routine maintenance activities was determined.

This interim report presents results of the above survey, describes an integer programming optimization model and discusses the relevant input data requirements. The model proposed can be applied at the unit, subdistrict, district or even at the statewide level. A numerical example based on routine maintenance information obtained from the IDOH is worked out to illustrate the salient features of the programming procedure.

CHAPTER 2

SURVEY ON ROUTINE MAINTENANCE NEEDS PRIORITY AND INFLUENCE OF REHABILITATION SCHEDULE

2.1 Introduction

In Indiana, priority is recorded as part of semi-monthly schedules of routine maintenance activities prepared by general foremen for review by Sub-district Superintendents [8]. An example of this schedule is shown in Figure 2.1. Each activity is also assigned to one of four work control categories - unlimited, limited, variable and overhead. The work control category guides the work schedulers on their authority to deviate from annual work program quantities prepared for the budget. Unlimited activities such as Machine Mowing and Cleaning minor Drainage Structures are performed when needed and in amounts required to correct deficiency with no quantity limitations. Limited activities are those for which quantities can be estimated and firmly adhered to. For example, Inspecting Minor Drainage Structures can be set at a fixed number of times yearly, and so on. Control of work quantities is normally exercised by planned work units. For variable activities, e.g. Brush Cutting, planned amount of work is not urgently needed each year. Overhead activities are necessary work like Rest Area Attendant Training, and so on, not directly related to maintenance of roadway or structural elements [8,9]. Though the general guidelines are provided, priorities need to be determined for undertaking routine maintenance activities. This chapter discusses a survey of various district and subdistrict highway personnel in Indiana to assess rou-

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DIVISION OF MAINTENANCE

SEMI-MONTHLY SCHEDULE

DISTRICT/SUB-DISTRICT 71 GREEN, UNIT 1

SCHEDULE PERIOD – FROM 10/16/87 TO 10/31/87

JOB NO. OR PRIORITY	ACT NO.	ACTIVITY DESCRIPTION	LOCATION OF WORK	CREW SIZE	× DAYS	= MAN DAYS	M	T	W	T	F		M	T	W	T	F				
							DAY OF WEEK/DATE														
1	201	SHALLOW PATCHING	75 (US50 to I60)	6	5	30															
2	221	MACHINE MOWING	26 (WESTPORT TO UNION)	4	4	16															
3	231	CLEAN/RESHAPE DITCHES	75 (26 TO GRANT)	7	5	35							X	X	X	X	X				
4	222	BRUSH CUT AND TRIM TREES	250 (PINEVIEW TO GALENA)	5	3	15															
5	265	STOCK WINTER MATERIALS	UNIT YARD	1	10	10															
6	269	ERECT SNOW FENCE	75N. (FROM GREEN TO CO. LINE)	4	2	8															
	117	TRAINING	SNOW ROUTES DRY RUNS	10	1	10															
	112	SUPERVISION		1	10	10															
Act.	276	SPOT LITTER PICKUP	US50 (GALENA TO HAMILTON)	2	3																
Act.	232	CLEAN/INSPECT DRAINAGE STRUCTURES	250 (GREEN TO RETREAT)	2	2																

NUMBER OF MEN ASSIGNED	×	NUMBER OF WORK DAYS IN PERIOD	=	TOTAL MAN – DAYS	–	MAN – DAYS OF LEAVE	=	AVAILABLE MAN – DAYS
13	×	10	=	130	–	8	=	122

TOTAL MAN DAYS PLANNED: 134

SHEET 1 OF 1

PLANNED BY Charlie Jones DATE 10 /14 /87

APPROVED BY Andy DATE 10 /14 /87

State Form 2

Figure 2.1 Semi-Monthly Schedule for Indiana Department of Highways.

tine maintenance needs priority and ranking. The results provide consensus view of unwritten but important daily practices governing routine maintenance practices of subdistrict field personnel and District Maintenance Engineers of the Indiana Department of Highways.

Another aspect of the survey concerns with the influence of rehabilitation schedule. It is a common practice that a highway agency would adjust its routine maintenance program accordingly once a rehabilitation project on a given highway section is scheduled. Depending upon the time in advance the decision to rehabilitate is made known to maintenance personnel, either the long term (e.g. yearly or half-yearly) or short term (e.g. weekly or biweekly) maintenance program or both would be affected. Proper adjustments of routine maintenance program to cater to a scheduled rehabilitation helps ensure cost-effective utilization of available routine maintenance funds and resources. There is, therefore, a need to consider the influence of rehabilitation schedule in a formal optimization programming of routine maintenance activities.

2.2 The Survey

Based on a randomized selection process used in earlier studies by Montenegro and Sinha [6], 36 field staff (9 Maintenance or Field Engineers, 8 General Foremen or Superintendent and 19 Unit Foremen) from eleven subdistricts in the six IDOH districts were surveyed. Sixteen of the staff surveyed were from the northern region and twenty were from the southern region of Indiana (Table 2.1). The distribution of staff from the various subdistricts was such that the effects of two distinct climatic conditions as found in the

Table 2.1 Distribution of Field Staff Surveyed.

District	Subdistrict	Region	Number of Field Staff Interviewed		
			Engineers	General Foremen/ Superintendent	Unit Foremen
Fort Wayne	Fort Wayne	North	2	1	3
	Bluffton	North	--	1	2
La Porte	La Porte	North	1	--	--
	Plymouth	North	--	1	5
Greenfield	Greenfield	South	3	--	--
	Anderson	South	--	--	4
Seymour	Bloomington	South	--	1	1
	Columbus	South	--	1	1
Vincennes	Petersburg	South	1	1	1
Crawfordsville	Crawfordsville	South	2	1	1
	Veedersburg	South	--	1	1

Table 2.2 List of Maintenance Activities Investigated.

Code	Description
201	Shallow Patching
202	Deep Patching
203	Premix Leveling
204	Full Width Shoulder Seal
205	Seal Coating- Chip Seal
206	Sealing Longitudinal Cracks and Joints
207	Crack Sealing
208	Sand Seal
210	Spot Repair of Unpaved Shoulders
211	Blading of Unpaved Shoulders
212	Clipping Unpaved Shoulders
213	Reconditioning Unpaved Shoulders
231	Clean and Reshape Ditches
234	Motor Patrol Ditching

colder northern region and the relatively warmer southern region could be assessed. The subdistrict and field staff interviewed included field engineers, superintendents and/or general foremen and unit foremen.

2.2.1 Assignment of Priority Ratings

Three main factors affecting routine maintenance priority ratings were considered in the survey. The factors included maintenance activity type, distress severity of the road element needing the activity and the highway class. Fourteen routine maintenance activities involving pavement, shoulder and drainage were investigated. Table 2.2 shows a list of these activities.

The highway classes defined were Interstate and Other State Highways (OSH). OSH was further broken into two categories: high traffic OSH with more than 400 vehicles per day (vpd), and low traffic OSH with less than 400 vpd. The traffic volume classification was chosen to provide broad guidelines for differentiating maintenance priorities of the various highways. For conditions, three levels of distress severity were considered, namely, severe, moderate and slight.

A simple calculation shows that there are 14x3x3 = 126 entries to be priority rated. Simultaneous rating of all 126 entries is out of question as it is way beyond the capability of a normal human. Pairwise comparison is theoretically possible but practically infeasible due to the large number of possible combinations. To reduce the problem to a manageable size, the contributing factors were divided into two parts and carried out independently. Figure 2.2 shows the flow diagram of the survey. One part of the survey dealt with assigning priority scores to individual routine maintenance activities in

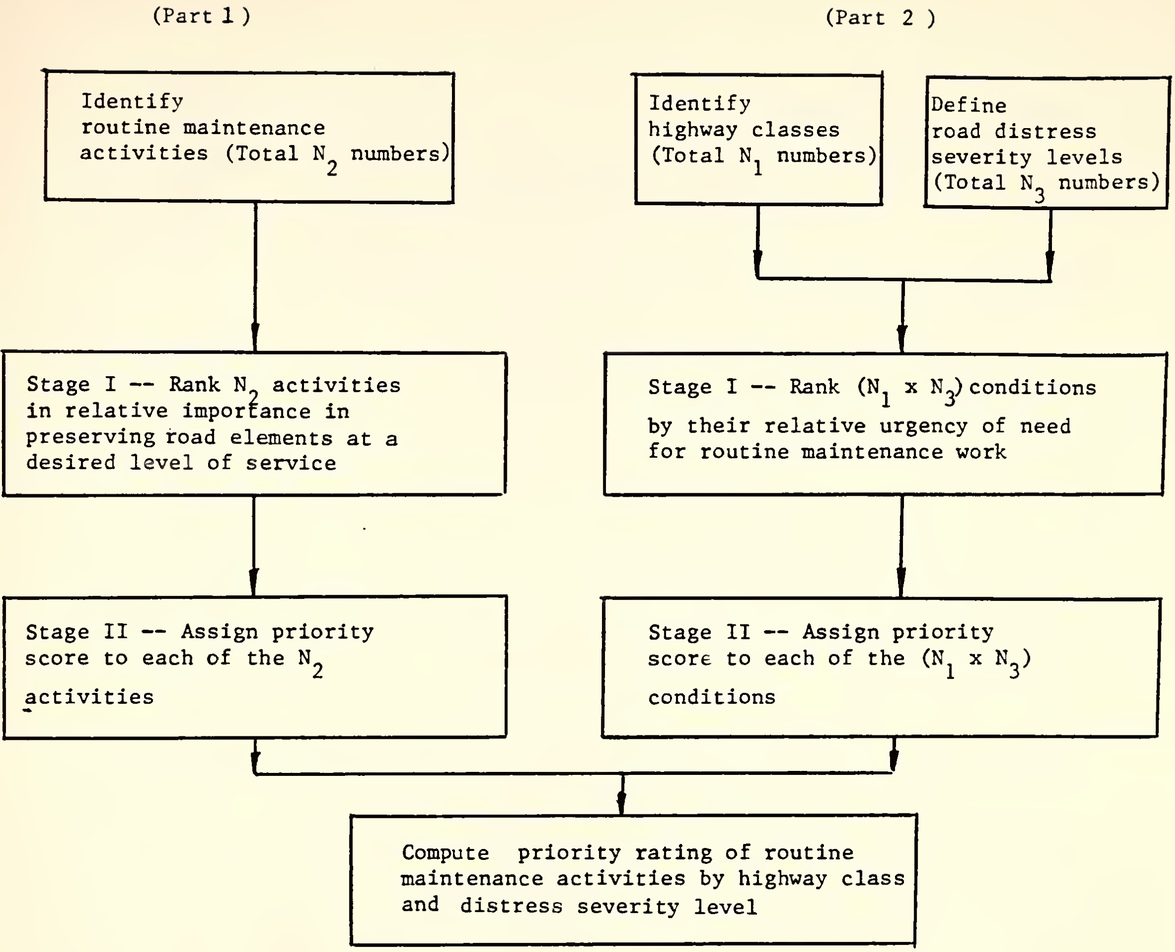


Figure 2.2 Activity Flow Chart for the Partitioned Two-Stage Survey Procedure

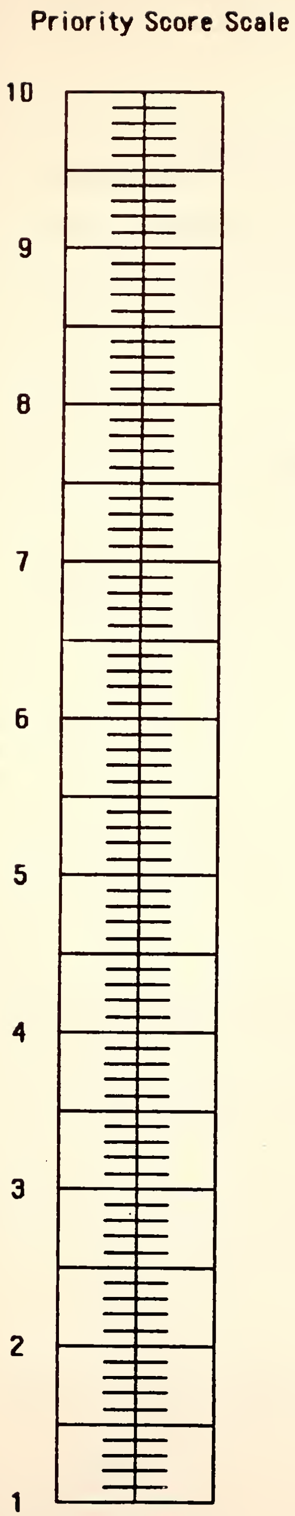
accordance with their relative importance in preserving highway conditions at a desired level. In the other part, priority scores were assigned to different road elements of various highway classes by distress severity level according to their relative urgency of need for maintenance work.

To further aid raters in arriving at the priority scores of their choice quickly and efficiently, the following measures were taken. (a) A two-stage rating procedure was adopted. Raters were first asked to rank the entries with all potenital ties considered. Keeping the order of the ranks, the raters were next asked to assign priority score to each on a 10-point scale as shown in Figure 2.3. (b) Instead of using tables or forms, a set of cards with a different entry written on each, was given to each rater. By allowing each rater to place the cards in rank order and then move them into relative positions above or below each other along the 10-point scale, realistic priority scores could be assigned fairly quickly. The experience of the survey indicated that the rating procedure was well received by raters, and satisfactory results were obtained in an unambiguous manner.

An alternative procedure would have been to adopt a tree-like survey structure. The raters would first rate all maintenance activities as in Part 1 of the survey in Figure 2.2, then proceed to repeat N_1 number of times the Part 2 rating process in Figure 2.2. However, this procedure is highly time consuming. Consequently, the survey procedure in Figure 2.2 was used in this study.

2.2.2 Influence of Rehabilitation Schedule

A concept of interference period is introduced in this study to account



Instruction for Rater

Step 1. You are given 14 routine maintenance activity types, each written on a small card. Go through and read the activity types carefully.

Step 2. (Ranking Assignment) Rank the cards on your desk in accordance with the importance of each activity type in preserving road condition at a desired level. Put the most important activity at the top, followed by other activities in the order of decreasing importance. Ties are allowed.

Step 3. Carefully review the ranking in Step 2. Make changes if necessary.

Step 4. Move the top priority card to the top (i.e. a score of 10) of the scale on this instruction sheet. Next, move one card at a time, in sequence of decreasing importance, to the score and assign a score to each by comparing with the activity immediately above it. Continue until all the cards are placed on the scale.

Step 5. If the last card does not have a score of 1, adjust the scores (except the top score) so that the lowest priority activity has a score of 1.

Step 6. Carefully review the priority scores assigned. Make changes if necessary.

Figure 2.3 Priority Rating Scale and Rater Instruction.

for the influence of rehabilitation projects on routine maintenance programming. An interference period, d, is defined as the time period during which a given routine maintenance activity would be suspended, due solely to the scheduling of a rehabilitation work.

Figure 2.4 shows a sketch which depicts graphically the concept of interference period. Two other terms are also introduced in Figure 2.4. The term maintenance operation suspension period, symbolically represented by X, refers to the length of time prior to a rehabilitation work that highway maintenance personnel decide to suspend all maintenance activities. The second term is the suspension period for a given maintenance activity. It represents the length of time prior to a rehabilitation work that the maintenance activity concerned would not be carried out at all. It is important to note that the length of a maintenance activity suspension period is a function of the severity of distress to be corrected, and the class of the highway on which the maintenance activity is considered.

Based upon the definitions given above, the following relationship can be written:

Maintenance operation suspension period

$$X_i = \min x_{ijk} \qquad i=1,2,\ldots N_1,\ j=1,2,\ldots N_2,\ k=1,2,\ldots N_3 \tag{2.1}$$

Interference period

$$d_{ijk} = x_{ijk} - X_i \qquad i=1,2,\ldots N_1,\ j=1,2,\ldots N_2,\ k=1,2,\ldots N_3 \tag{2.2}$$

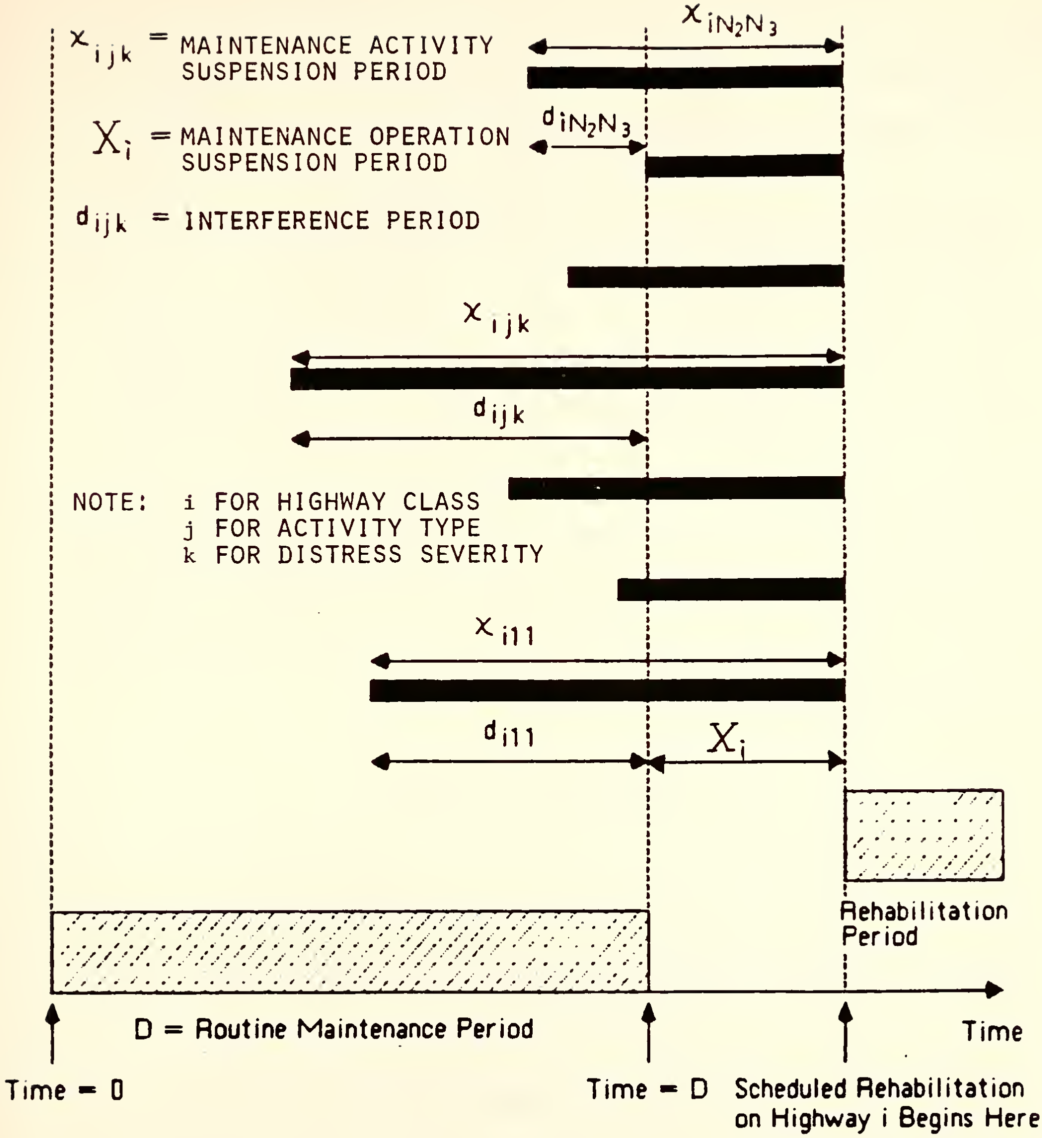


Figure 2.4 Influence of Rehabilitation Constraint.

where

X_i = maintenance operation auspension period on highway i

x_{ijk} = suspension period for routine maintenance activity j on highway i with distress condition level k,

d_{ijk} = interference period during which no maintenance activity type j would be performed on highway i with distress condition level k,

N_1 = total number of highways,

N_2 = total number of routine maintenance activities,

N_3 = total number of distress condition levels.

The above relationships clearly show that the basic quantities that need to be determined are the maintenance activity suspension periods, x_{ijk}. These quantities were obtained from survey by asking each interviewee to estimate the length of suspension period for different maintenance activity-highway class distress severity level combinations.

2.3 Analysis of Survey Data

This section presents the results and analyses of the survey data on the following two aspects: (a) priority ratings of routine maintenance activities by highway class and maintenance need urgency level; (b) influence of rehabilitation constraint on routine maintenance programming.

2.3.1 Priority Ratings of Routine Maintenance Activities

The data collected from stages I and II of the survey (see Figure 2.2) are presented in Tables 2.3 through 2.6. These data are presented in the form of bar charts in Appendix A. Let f_1 and f_2 represent the priority scores obtained from the two stages, then the final priority ratings of all routine

Table 2.3 Average Ranking of Highway Class and Condition Severity.

Highway Class	Condition Level	Northern Region		Southern Region	
		Average	95% Conf. Int.	Average	95% Conf. Int.
Interstate	Severe	1	1	1	1
	Moderate	3	2 - 3	4	3 - 4
	Slight	6	5 - 7	7	6 - 8
Other State Highways (High Volume)	Severe	2	2 - 3	2	2
	Moderate	5	4 - 5	5	4 - 5
	Slight	8	7 - 8	7	7 - 8
Other State Highways (Low Volume)	Severe	5	3 - 6	4	3 - 5
	Moderate	7	6 - 8	7	6 - 8
	Slight	9	9	9	9

Table 2.4 Average Priority Scores of Highway Class and Condition Severity.

Highway Class	Condition Level	Northern Region		Southern Region	
		Average	95% Confidence Interval	Average	95% Confidence Interval
Interstate	Severe	10.0	10.0 - 10.0	10.0	10.0 - 10.0
	Moderate	8.7	8.2 - 9.2	8.1	7.3 - 8.6
	Slight	6.3	4.7 - 7.8	4.1	2.8 - 5.4
Other State Highways (High Volume)	Severe	9.4	8.9 - 9.9	9.6	9.5 - 9.7
	Moderate	7.8	7.2 - 8.3	7.3	6.8 - 7.9
	Slight	4.3	3.0 - 5.6	3.7	2.2 - 5.1
Other State Highways (Low Volume)	Severe	7.4	6.4 - 8.3	7.6	6.0 - 9.3
	Moderate	4.9	3.6 - 6.4	3.8	2.2 - 5.5
	Slight	1.0	1.0 - 1.0	1.0	1.0 - 1.0

Table 2.5 Average Ranking of Highway Maintenance Activities.

Maintenance Activities		North		South	
Code	Description	Ave.	95% Conf. Int.	Ave.	95% Conf. Int.
201	Shallow Patching	1	1 - 2	3	1 - 4
202	Deep Patching	2	1 - 3	2	1 - 2
203	Premix Leveling	6	3 - 8	8	5 - 11
204	Full Width Shoulder Seal	10	8 - 12	12	11 - 13
205	Seal Coating - Chip Seal	8	6 - 10	11	9 - 13
206	Seal Long. Cracks & Joints	7	5 - 10	8	6 - 11
207	Crack Sealing	7	4 - 9	7	4 - 10
208	Sand Seal	9	6 - 11	12	11 - 13
210	Spot Repair Unp. Shoulders	5	3 - 7	7	5 - 9
211	Blading Unp. Shoulders	6	4 - 8	9	7 - 11
212	Clip Unpaved Shoulders	10	8 - 12	8	6 - 11
213	Recondition Unp. Shoulders	11	10 - 12	7	5 - 10
231	Clean & Reshape Ditches	10	7 - 13	5	3 - 7
234	Motor Patrol Ditching	13	12 - 14	7	5 - 10

Table 2.6 Average Priority Scores of Highway Maintenance Activities.

Maintenance Activities		Northern Region		Southern Region	
Code	Description	Ave.	95% Confidence Interval	Ave.	95% Confidence Interval
201	Shallow Patching	9.9	9.8 - 10.0	9.4	8.8 - 10.1
202	Deep Patching	9.6	9.2 - 10.0	9.6	9.1 - 10.0
203	Premix Leveling	7.2	5.5 - 8.9	5.4	2.9 - 7.9
204	Full Width Shoulder Seal	4.9	3.2 - 6.6	3.5	2.1 - 5.0
205	Seal Coating - Chip Seal	6.4	5.4 - 7.3	4.4	2.8 - 6.0
206	Sealing Longitudinal Cracks and Joints	6.7	5.3 - 8.1	5.7	4.1 - 7.3
207	Crack Sealing	6.8	5.3 - 8.4	6.5	4.6 - 8.4
208	Sand Seal	5.6	3.8 - 7.3	2.9	1.7 - 4.2
210	Spot Repair of Unpaved Shoulders	7.8	6.1 - 9.6	7.1	5.8 - 8.4
211	Blading of Unpaved Shoulders	7.0	5.1 - 8.8	5.9	4.2 - 7.5
212	Clipping Unpaved Shoulders	4.6	2.8 - 6.4	5.8	4.2 - 7.4
213	Reconditioning Unpaved Shoulders	4.2	2.7 - 5.6	6.5	4.4 - 8.6
231	Clean and Reshape Ditches	3.7	1.6 - 5.9	7.8	6.7 - 8.8
234	Motor Patrol Ditching	1.9	0.3 - 3.5	6.6	4.9 - 8.4

maintenance activities can be computed as follows:

$$F_{ijk} = (f_2)_{ik} \times (f_1)_j \quad i=1,2,..N_1,\ j=1,2,..N_2,\ k=1,2,..N_3 \qquad (2.3)$$

where

F_{ijk} = priority rating for routine maintenance activity i on highway i with distress severity level k,

$(f_2)_{ik}$ = routine maintenance priority score for combination of highway class i and distress severity level k in relation to all other combinations of the two factors as obtained from Part 2 of the survey,

$(f_1)_j$ = routine maintenance priority score for routine maintenance activity type j in relation to all other routine maintenance activity types as obtained from Part 1 of the survey.

N_1, N_2 and N_3 are as defined in Eqs. (2.1) and (2.2).

It should be mentioned that, instead of taking the product of f_1 and f_2, a different set of F_{ijk} values may be computed by adding up f_1 and f_2. A comparison of the two procedures is presented in Appendix C.

Using the relationship in Eq. (2.3) and the data in Tables 2.4 and 2.6, the priority ratings for all the routine maintenance activities surveyed are computed and recorded in Table 2.7. Both the priority rating scores for the North and the South regions are presented in the same table. These priority ratings provide the necessary information on the relative importance of various maintenance activities. The values as computed in Table 2.7 can be input directly as maintenance activity weighting factors in an optimization model for routine maintenance programming.

2.3.2 Further Analysis on Priority Rating Data

Further to the primary objective of determining priority ratings for

Table 2.7 Priority Ratings of Routine Maintenance Activities by Highway Class and Distress Severity Level.

Routine Maintenance Activity Code	Interstate			High Volume OSH			Low Volume OSH		
	Distress Severity Lev.			Distress Severity Lev.			Distress Severity Lev.		
	Severe	Moderate	Slight	Severe	Moderate	Slight	Severe	Moderate	Slight
201	99 (N)	86 (N)	62 (N)	93 (N)	77 (N)	43 (N)	73 (N)	49 (N)	10 (N)
	94 (S)	76 (S)	39 (S)	90 (S)	70 (S)	35 (S)	71 (S)	36 (S)	9 (S)
202	96 (N)	84 (N)	60 (N)	90 (N)	75 (N)	41 (N)	71 (N)	47 (N)	10 (N)
	96 (S)	78 (S)	40 (S)	92 (S)	70 (S)	36 (S)	73 (S)	35 (S)	10 (S)
203	72 (N)	63(N)	45 (N)	68 (N)	56 (N)	31 (N)	53 (N)	35 (N)	7 (N)
	54 (S)	44 (S)	22 (S)	52 (S)	39 (S)	20 (S)	38 (S)	21 (S)	5 (S)
204	49 (N)	43 (N)	31 (N)	46 (N)	38 (N)	21 (N)	36 (N)	24 (N)	5 (N)
	35 (S)	28 (S)	14 (S)	34 (S)	26 (S)	13 (S)	27 (S)	13 (S)	4 (S)
205	64 (N)	56 (N)	40 (N)	60 (N)	50 (N)	28 (N)	47 (N)	31 (N)	6 (N)
	44 (S)	36 (S)	18 (N)	42 (S)	32 (S)	16 (S)	33 (S)	16 (S)	4 (S)
206	67 (N)	58 (N)	42 (N)	63 (N)	52 (N)	29 (N)	50 (N)	33 (N)	7 (N)
	57 (S)	46 (S)	23 (S)	55 (S)	42 (S)	21 (S)	43 (S)	22 (S)	6 (S)
207	68 (N)	59 (N)	43 (N)	64 (N)	53 (N)	29 (N)	50 (N)	33 (N)	7 (N)
	65 (S)	53 (S)	27 (S)	62 (S)	47 (S)	24 (S)	50 (S)	25 (S)	7 (S)
208	56 (N)	49 (N)	35 (N)	53 (N)	44 (N)	24 (N)	41 (N)	27 (N)	6 (N)
	29 (S)	23 (S)	12 (S)	28 (S)	21 (S)	11 (S)	22 (S)	11 (S)	3 (S)
210	78 (N)	68 (N)	49 (N)	73 (N)	61 (N)	34 (N)	58 (N)	38 (N)	8 (N)
	71 (S)	58 (S)	29 (S)	68 (S)	52 (S)	26 (S)	54 (S)	27 (S)	7 (S)
211	70 (N)	61 (N)	44 (N)	67 (N)	55 (N)	30 (N)	52 (N)	34 (N)	7 (N)
	59 (S)	48 (S)	24 (S)	57 (S)	43 (S)	22 (S)	46 (S)	12 (S)	6 (S)
212	46 (N)	40 (N)	29 (N)	43 (N)	36 (N)	20 (N)	34 (N)	23 (N)	5 (N)
	58 (S)	46 (S)	23 (S)	55 (S)	42 (S)	21 (S)	43 (S)	22 (S)	6 (S)
213	42 (N)	37 (N)	26 (N)	39 (N)	33 (N)	18 (N)	31 (N)	21 (N)	4 (N)
	65 (S)	53 (S)	27 (S)	62 (S)	47 (S)	24 (S)	50 (S)	25 (S)	7 (S)
231	37 (N)	32 (N)	23 (N)	35 (N)	29 (N)	16 (N)	27 (N)	18 (N)	4 (N)
	78 (S)	63 (S)	32 (S)	75 (S)	57 (S)	29 (S)	59 (S)	30 (S)	8 (S)
234	19 (N)	17 (N)	12 (N)	18 (N)	15 (N)	8 (N)	14 (N)	9 (N)	2 (N)
	66 (S)	53 (S)	27 (S)	63 (S)	48 (S)	24 (S)	50 (S)	32 (S)	7 (S)

Note: (N) stands for North Region, and (S) stands for South Region.

various routine maintenance activities, the data gathered can be analyzed in more details to provide other useful information. As an illustration, this section presents an in-depth analysis to compare the priority ratings of routine maintenance activities made by maintenance personnel of the North and South regions of Indiana.

Plotted in Figures 2.5, 2.6 and 2.7 are data obtained from Table 2.7 for routine maintenance activities on Interstate, high traffic volume OSH and low traffic volume OSH, respectively. Due to the large number of data points in Table 2.7, three plots instead of one were prepared for clarity of presentation. A 45-degree line of equality was also drawn in each plot for reference purpose.

In comparing the priority ratings from two different regions, it is important to note that the absolute values of individual ratings do not carry much meaning, it is their relative magnitudes within their own set of ratings that make the difference. For instance, rating panel A may award priority values of 20, 30, 40 and 50 to four different maintenance activities, while rating panel B awards 2, 3, 4 and 5, and panel C awards 30, 20, 50, 40 to the same activities. It is clear that there is no difference between panels A and B scores, and that panel C scores are slightly different from those of the two sets. An appropriate parameter to measure this difference would be the statistics known as the coefficient of correlation, r [10]. Panels A and B would give a r value of 1.0, which means a perfect linear association between the two sets of priority scores. Panels A and C or B and C produce a much lower r value equal to 0.60, indicating a relatively poor association between

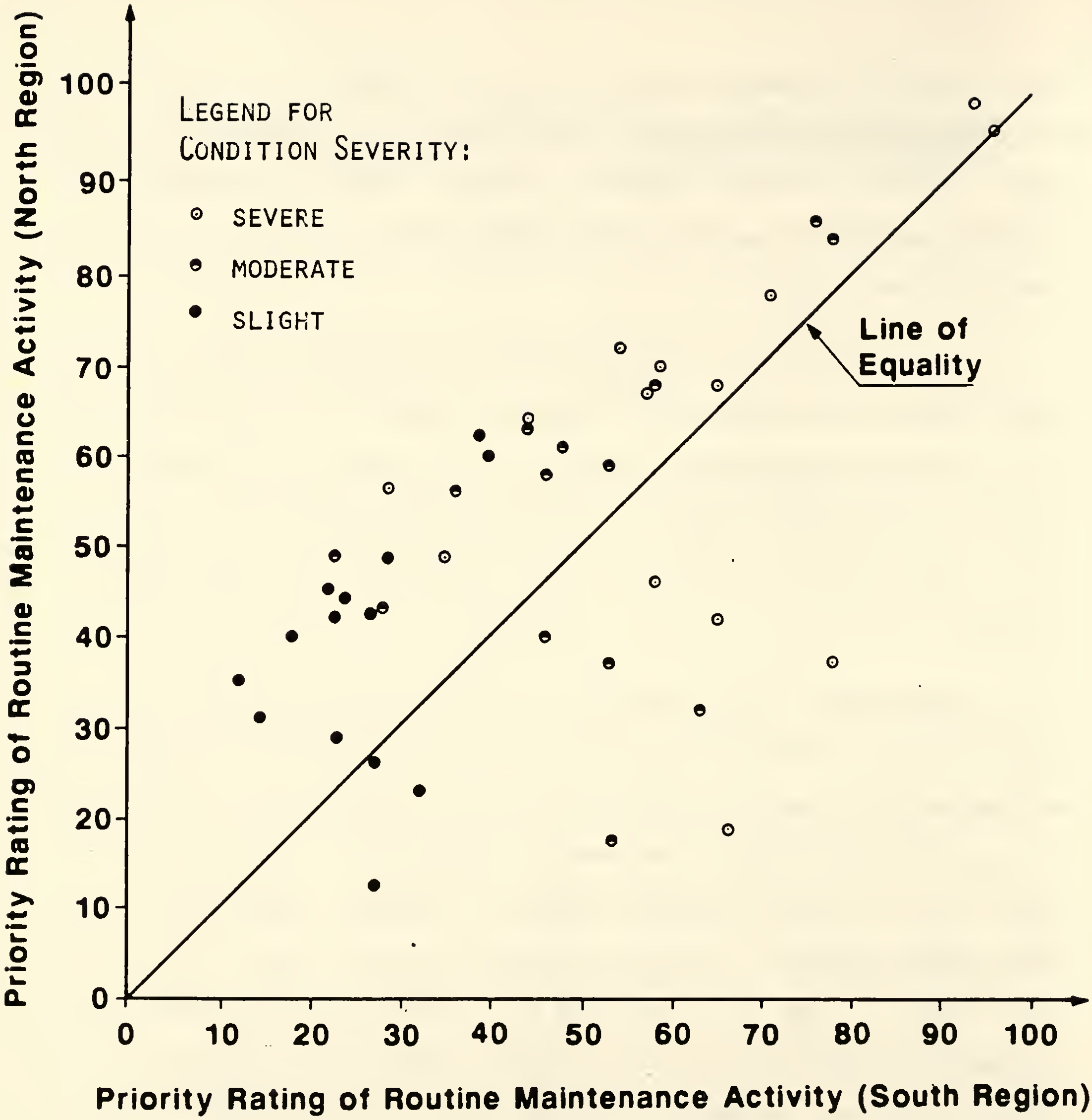


Figure 2.5 Comparison of North and South Region Priority Ratings for Routine Maintenance Activities on Interstate.

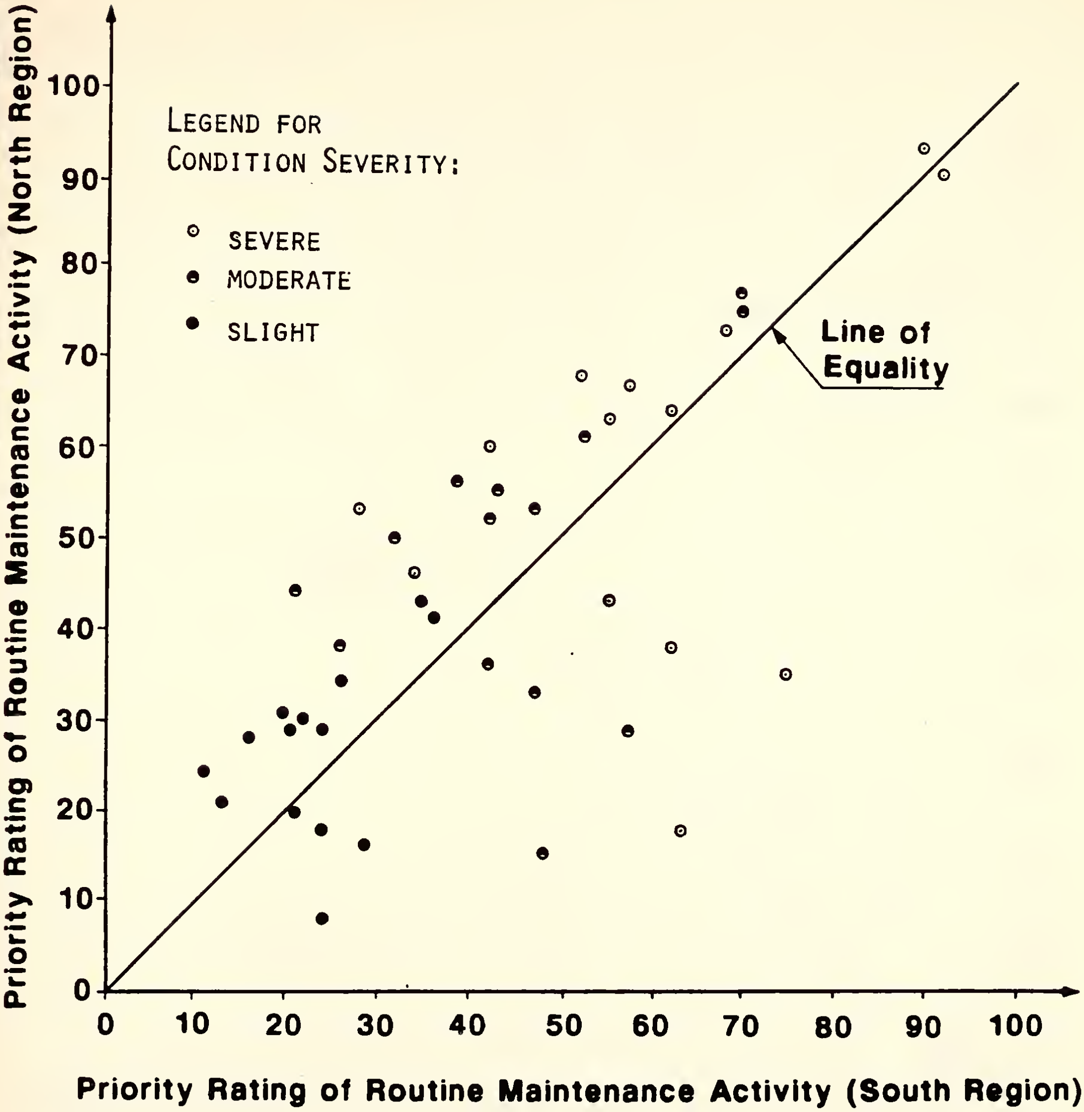


Figure 2.6 Comparison of North and South Region Priority Ratings for Routine Maintenance Activities on High Volume OSH.

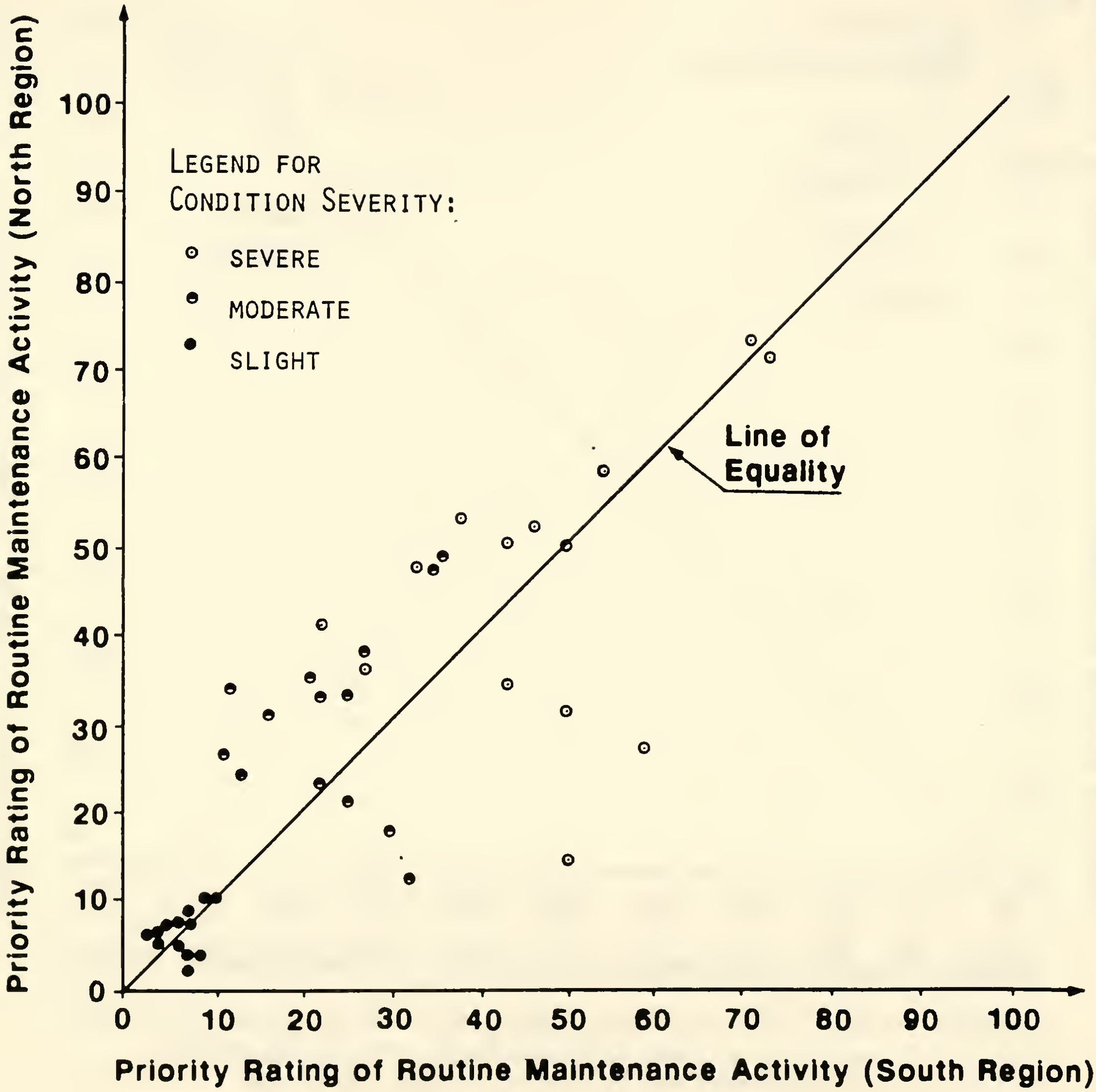


Figure 2.7 Comparison of North and South Region Priority Scores for Routine Maintenance Activities on Low Volume OSH.

the two sets compared.

Using all the 126 pairs of priority scores in Table 2.7, computation gives a value of r equal to 0.74. This shows that the agreement between the priority ratings of the North and South regions was only fair. However, a closer examination of the plots in Figures 2.5, 2.6 and 2.7 shows that (i) all the points that lie below the line of equality belong to the following four maintenance activities: 212, 213, 231 and 234; and (ii) all other data points tend to cluster relatively closely in a straight band pattern.

A revised computation confirms the above observation. Considering only the first 10 maintenance activities in Table 2.7, a r value of 0.95 was obtained. For the last four maintenance activities, i.e. activities 212, 213, 231 and 234, the r value computed was 0.69. These results reveal that the North and South maintenance personnel were in excellent agreement over the priority ratings of most maintenance activities, except for the four activities mentioned above. These four activities are mainly drainage-related maintenance work. The South region personnel placed more priority on these activities as compared to their counterpart in the North region. This is possibly due to climatic and topographical differences between the North and South. The South has steeper and more rolling to hilly terrain. It also has more rainfall, with an annual average of more than 40 in. compared to about 35 in. in the North.

The higher priority assigned to the last four maintenance activities by the South region maintenance personnel resulted in lower priority values for other activities against the corresponding values awarded by the North region

maintenance personnel. However, the relative priority of these other activities assigned by the two rating groups were apparently quite similar. This explains why the data points of these activities in all the three plots had appeared to be shifted upward approximately parallel to the line of equality, at the same time maintaining a high coefficient of correlation.

A study of the priority rankings in Table 2.6 indicates that both the North and South region maintenance personnel give highest priorities to pavement-related activities such as shallow and deep patching, premix leveling and crack sealing. The main discrepancy arises when the South region maintenance personnel assigned appreciably higher priorities to the last four drainage-related activities. Taking these four activities aside, the two groups of maintenance personnel appeared to be quite agreeable upon the relative priority rankings of the remaining activities. These observations concurs with the comments made in the preceding paragraph.

Table 2.8 lists the coefficients of correlation values for different groupings of routine maintenance activities. It can be seen that under each highway class, the same relationship between the priority rating distribution patterns of the North and South regions persists. In graphical form, it can be noticed that the pattern of comparison plot seen in Figure 2.5 for Interstate was repeated very closely in the plot in Figure 2.6 for OSH with high traffic volume, and again in Figure 2.7 for OSH with low traffic volume. This indirectly reflects a measure of consistency in the rating results. The partitioning technique and the two-stage procedure used in the survey process appeared to have produced logical realistic ratings from the raters.

Table 2.8 Coefficients of Correlation Between Priority Scores of Routine Maintenance Activities Obtained for the North and South Regions of Indiana.

Group of Maintenance Activities	Interstate	OSH with High Traffic Volume	OSH with Low Traffic Volume	All Highways Combined
First 10 Activities in Table 2.7	0.97	0.96	0.94	0.95
Activities 212, 213, 231 and 234	0.44	0.61	0.78	0.69
All 14 Activities in Table 2.7	0.60	0.69	0.80	0.74

Comparing the three plots in Figures 2.5, 2.6 and 2.7, it is observed that there exists a tendency of the general data points' position to shift toward the low priority area at the lower left-hand corner of the plots, as one moves from Interstate to OSH with high traffic volume, and then to OSH with low traffic volume. This roughly reflects the priority rankings of various highway classes depicted in Table 2.4.

2.3.3 Influence of Rehabilitation Schedule

Knowing the rehabilitation schedule for a road usually leads to a suspension of some routine maintenance activities. This influence of rehabilitation schedule on routine maintenance program can be expressed in terms of maintenance activity suspension periods defined in Section 2.2.2. Survey interviewees were asked to write down the length of suspension period they would consider for each routine maintenance-distress condition level-highway class combination, even if certain activities are not performed by their organizations. For example, IDOH does not undertake chip sealing or sand sealing on Interstates. The results of the survey are presented in Tables 2.9 and 2.10. These data are presented in the form of bar charts in Appendix B. As explained in Section 2.2.2, these suspension period data are used to compute, by means of Eqs (2.1) and (2.2), routine maintenance interference periods which are in turn entered as rehabilitation constraint conditions for routine maintenance programming purpose.

Depending upon the highway maintenance agencies, and the size and management level of the network concerned, routine maintenance schedules may be planned for various time periods. Weekly, biweekly, monthly and even yearly

Table 2.9 Average Suspension Periods for Maintenance Activities - North Region (days)

Maintenance Activities Code	Description	Distress Condition Level	Interstate	OSH High Vol.	OSH Low Vol.
201	Shallow Patching	Severe	1	2	10
		Moderate	4	6	20
		Slight	13	28	61
202	Deep Patching	Severe	22	17	43
		Moderate	29	37	73
		Slight	47	65	75
203	Premix Leveling	Severe	157	216	233
		Moderate	187	218	248
		Slight	210	236	254
204	Full Width Shoulder	Severe	225	278	299
		Moderate	227	288	300
		Slight	251	284	297
205	Seal Coating (Chip Seal)	Severe	164	275	289
		Moderate	170	280	290
		Slight	190	285	289
206	Sealing Longitudinal Cracks and Joints	Severe	137	184	209
		Moderate	146	186	211
		Slight	151	198	208
207	Crack Sealing	Severe	67	126	175
		Moderate	81	136	178
		Slight	112	173	190
208	Sand Seal	Severe	221	287	307
		Moderate	224	285	308
		Slight	254	287	308
210	Spot Repair of Unpaved Shoulders	Severe	8	39	58
		Moderate	9	57	87
		Slight	15	88	115
211	Blading of Unpaved Shoulders	Severe	29	84	93
		Moderate	34	98	105
		Slight	67	132	143
212	Clipping Unpaved Shoulders	Severe	167	235	259
		Moderate	171	239	270
		Slight	183	260	273
213	Reconditioning Unpaved Shoulders	Severe	241	269	278
		Moderate	256	284	299
		Slight	256	294	301
231	Clean and Reshape Ditches	Severe	51	136	152
		Moderate	64	143	169
		Slight	139	195	196
234	Motor Patrol Ditching	Severe	138	191	193
		Moderate	163	207	210
		Slight	216	240	256

Table 2.10 Average Suspension Periods for Maintenance Activities - South Region (days)

Code	Description	Distress Condition Level	Interstate	USH High Vol.	DSH Low Vol.
201	Shallow Patching	Severe	4	6	12
		Moderate	17	23	35
		Slight	69	70	100
202	Deep Patching	Severe	29	55	66
		Moderate	50	90	98
		Slight	111	132	147
203	Premix Leveling	Severe	110	135	149
		Moderate	155	188	217
		Slight	211	265	282
204	Full Width Shoulder	Severe	194	205	231
		Moderate	251	261	288
		Slight	279	303	311
205	Seal Coating (Chip Seal)	Severe	156	182	249
		Moderate	183	236	288
		Slight	190	286	289
206	Sealing Longitudinal Cracks and Joints	Severe	137	184	209
		Moderate	250	264	282
		Slight	280	289	299
207	Crack Sealing	Severe	256	261	280
		Moderate	261	282	300
		Slight	291	311	316
208	Sand Seal	Severe	235	248	294
		Moderate	294	302	315
		Slight	298	314	317
210	Spot Repair of Unpaved Shoulders	Severe	36	78	101
		Moderate	93	139	160
		Slight	112	168	170
211	Blading of Unpaved Shoulders	Severe	80	84	139
		Moderate	176	171	209
		Slight	209	210	236
212	Clipping Unpaved Shoulders	Severe	116	187	211
		Moderate	175	226	273
		Slight	231	294	317
213	Reconditioning Unpaved Shoulders	Severe	154	180	226
		Moderate	227	268	305
		Slight	252	300	307
231	Clean and Reshape Ditches	Severe	105	143	181
		Moderate	162	205	244
		Slight	218	245	277
234	Motor Patrol Ditching	Severe	132	171	210
		Moderate	163	217	244
		Slight	205	257	285

programs are known to exist and used by different highway maintenance agencies [11,12,13,14]. The maintenance activity suspension period data covered a wide range that began with a minimum of 1 day to more than 300 days. Judging from the lengths of these suspension periods and the program duration of common routine maintenance schedules, it is easy to see that rehabilitation constraints indeed have an important impact on the scheduling of routine maintenance activities. There is therefore a certain need to incorporate the constraints imposed by pavement rehabilitation in the planning and programming of routine maintenance activities at different levels of a highway agency.

The data in Tables 2.9 and 2.10 clearly display several trends that one would readily anticipate. For a given routine maintenance, the suspension period on Interstate was shorter than on high volume OSH, and much shorter than on low volume OSH. This is a reflection of the relative importance of the three classes of highways in terms of maintenance priority as perceived by the maintenance personnel surveyed. Considering distress conditions, the data show that the `severe´ category had the shortest suspension period, followed by the `moderate´ and `slight´ categories in the order of increasing suspension period length. An analysis of variance (ANOVA) [15] conducted on the raw survey data of individual interviewees confirmed the above observations. Both highway class and distress condition level were found to have significant effects at a significance level of 0.01.

The length of suspension period of a maintenance activity is a measure of the extent in which scheduling of the activity is affected by a rehabilitation constraint. Maintenance activities with longer suspension periods are affected more than those with short suspension periods. Those activities with

very short suspension periods are affected only near the end of the maintenance program period. Table 2.11 separates, for each highway class, the 42 maintenance activity-distress severity combinations surveyed into 4 different categories in accordance with the length of their suspension periods. On the average for each highway class, more than half of the maintenance activities surveyed had long suspension periods. About one-third or less had short or very short suspension periods.

An examination of the data in Tables 2.9 and 2.10 reveals the following. The activities that had short and very short suspension periods are shallow patching (code 201), deep patching (code 202), and spot repair of unpaved shoulders (code 210), as well as crack sealing (code 207) and cleaning and reshaping ditches (code 231) on Interstate in the North region. Premix leveling (code 203), full width should seal (code 204), chip seal (code 205), sand seal (code 208), clipping unpaved shoulders (code 212), and reconditioning unpaved shoulders (code 213) are found to have long suspension periods.

2.3.4 Further Analysis on Rehabilitation Constraint Data

The data in Tables 2.9 and 2.10 are further analyzed in this section with respect to the differences and similarities between the survey results obtained from the North and South region maintenance personnel of Indiana. Data in the two tables are plotted in three graphs in Figures 2.8, 2.9 and 2.10 to facilitate presentation.

The data points in each plot cluster in a broad band with a positive slope. Coefficient of correlation computation gives r values of 0.70, 0.79 and 0.84 respectively for Figs. 2.8, 2.9 and 2.10. The overall coefficient of

Table 2.11 Suspension Period Distribution by Length for Maintenance Activity-Severity Level Combination by Highway Class.

Region	Highway Class	Length of Suspension Period			
		Very Short (Less than 1 month)	Short (1-3 months)	Medium (3-6 months)	Long (More than 6 months)
North	Interstate	9	7	13	13
	High Volume OSH	4	6	9	22
	Low Volume OSH	2	6	8	26
South	Interstate	3	4	15	20
	High Volume OSH	2	5	10	27
	Low Volume OSH	1	2	8	31

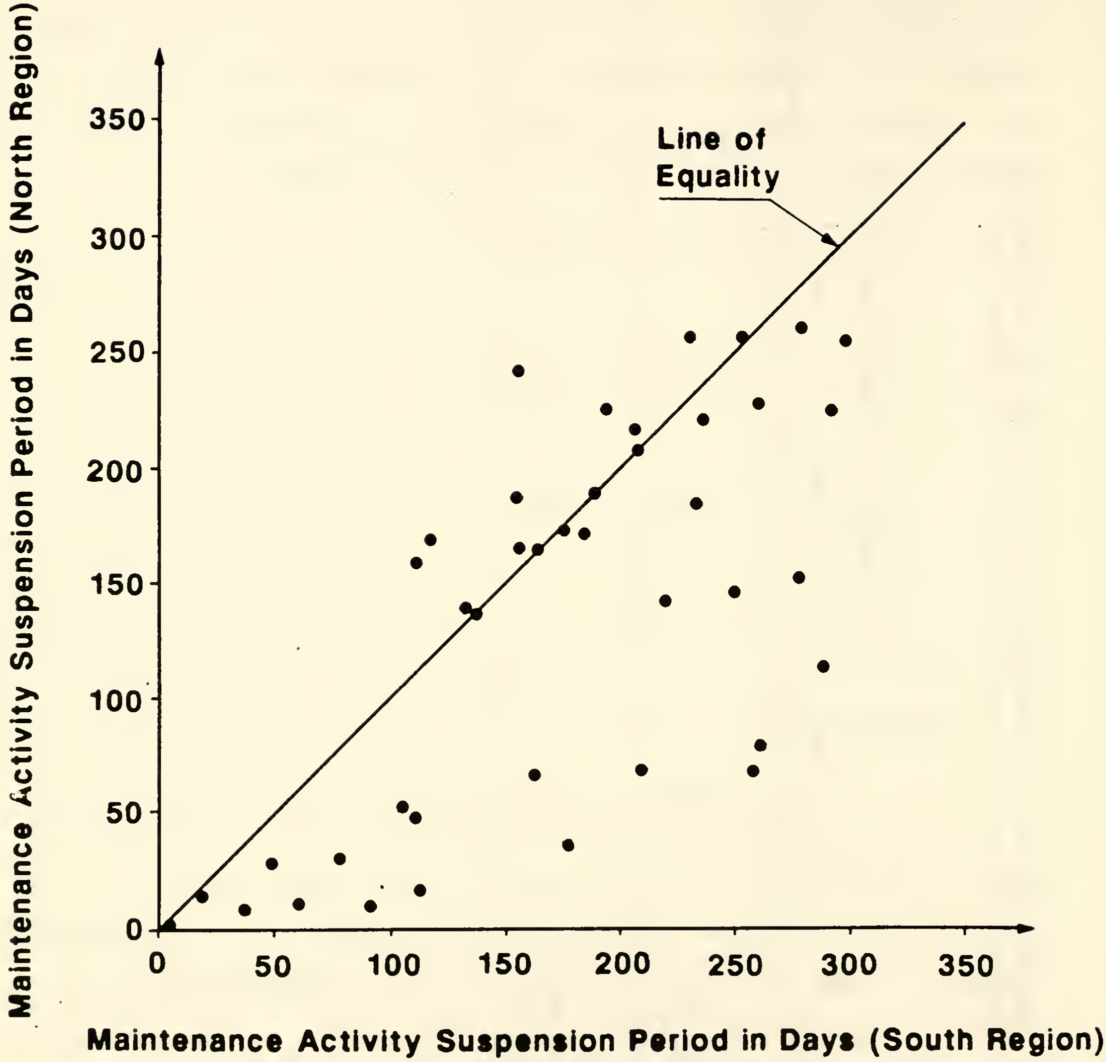


Figure 2.8 Comparison of Routine Maintenance Activity Suspension Periods on Interstate for North and South Regions.

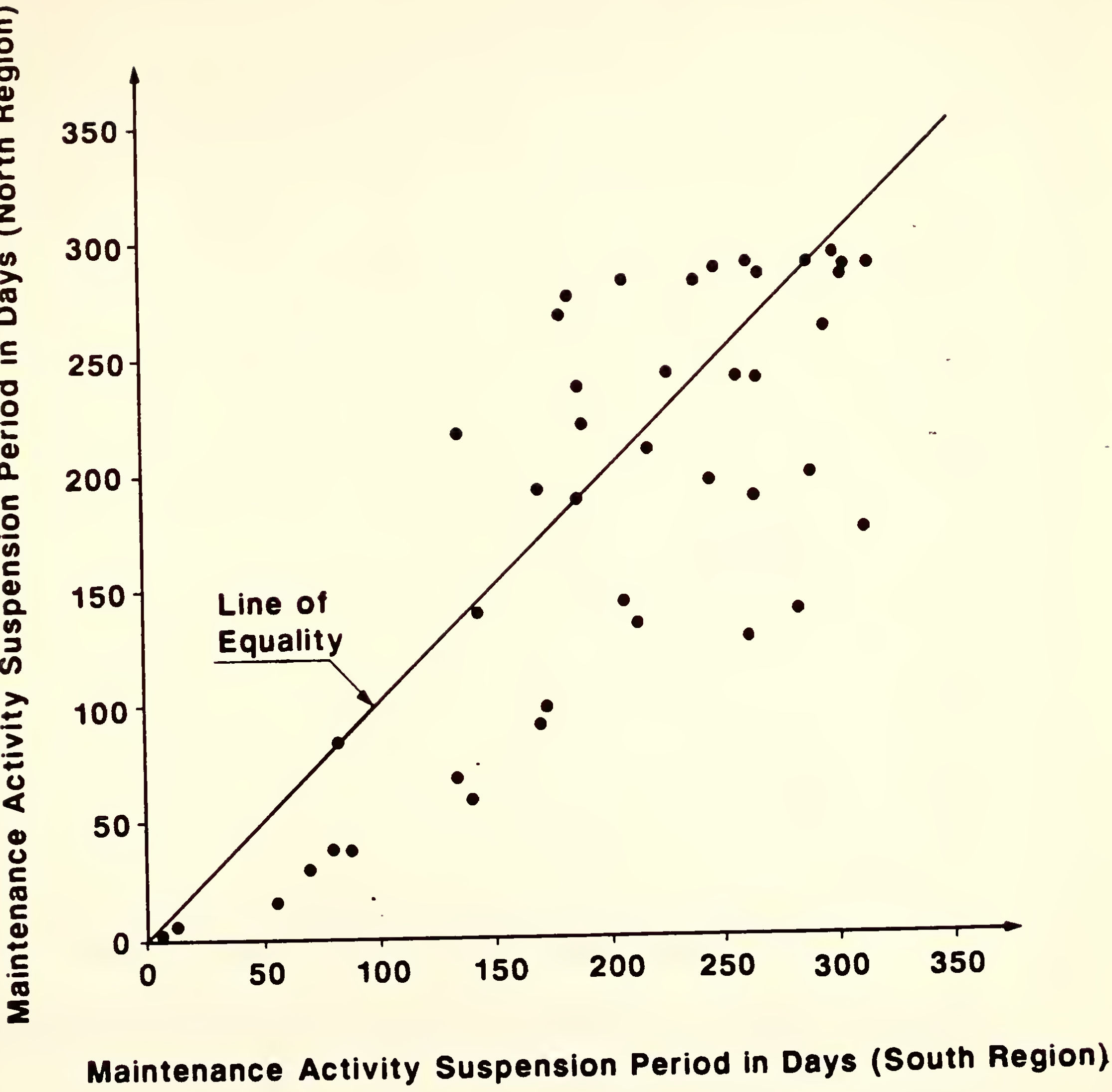


Figure 2.9 Comparison of Routine Maintenance Activity Suspension Periods on High Volume OSH for North and South Regions.

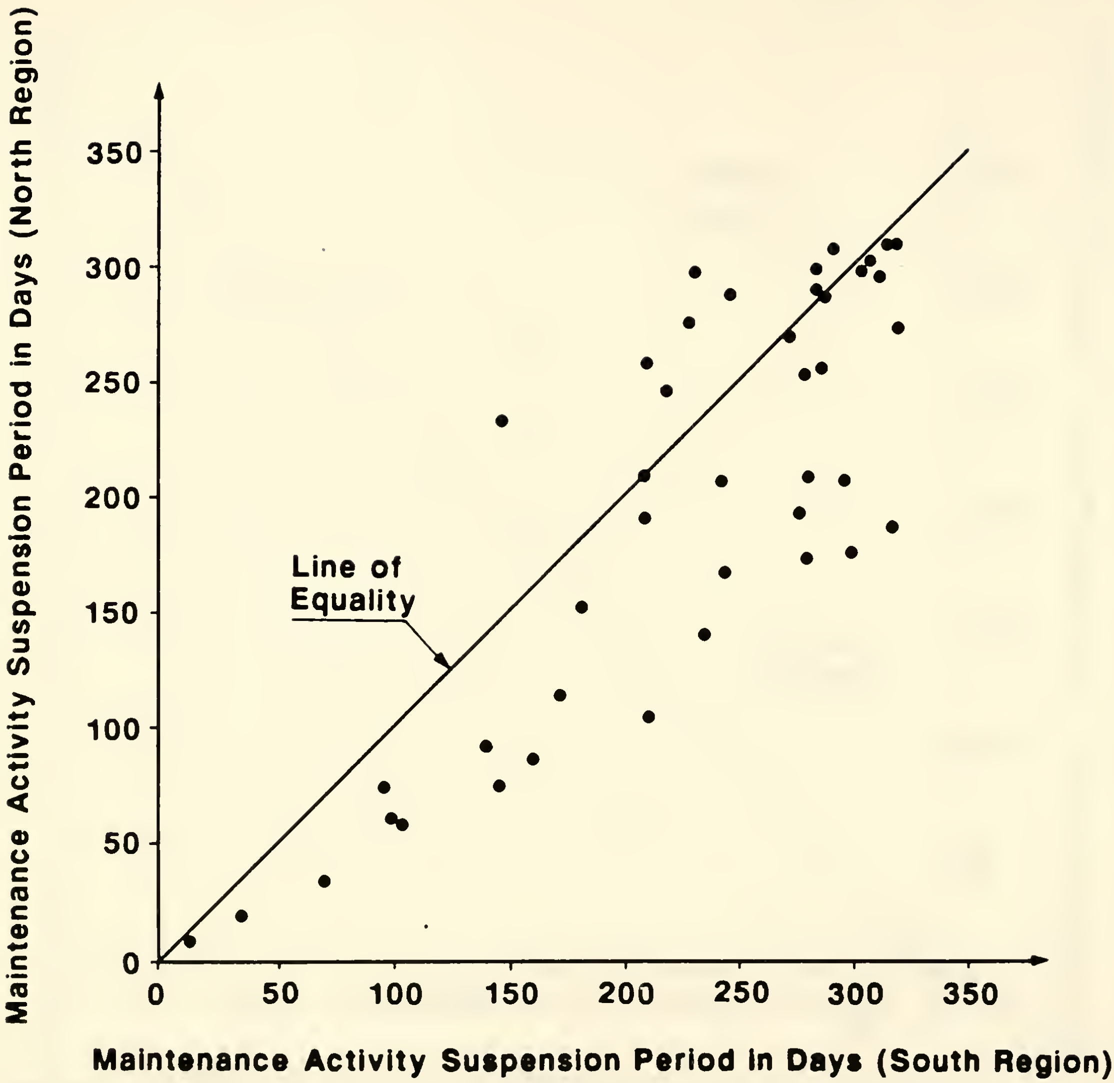


Figure 2.10 Comparison of Routine Maintenance Activity Suspension Periods on Low Volume OSH for North and South Regions.

correlation for all the data combined is 0.79. This indicates a fair degree of agreement or linear association between the responses from the North and South region maintenance personnel. In other words, maintenance activities that received short suspension periods in the North region also were given relatively short suspension periods in the South region, and vice versa.

The linear association mentioned above however does not mean equality of suspension periods for the North and South regions. Figures 2.8, 2.9 and 2.10, in fact, clearly show that majority of the data points fall below the equality line. This implies that the North region maintenance personnel, as compared to their South region counterpart, tended to assign shorter suspension periods for most of the maintenance activities surveyed. An inspection of the length distribution of suspension periods presented in Table 2.11 also reveals the same trend. To confirm this difference quantitatively, a statistical test for paired observations [10] was conducted for the 126 pairs of matched observations in Tables 2.9 and 2.10. A null hypothesis of no difference in the paired observations was tested against the alternative hypothesis that the North had shorter suspension periods than the South. The test concluded that the North had indeed assigned shorter suspension periods to routine maintenance activities at a significance level of 0.01.

This difference in maintenance practice between the two regions is interesting and worth looking into. Past research studies in Indiana [16,17,18] have pointed out the following differences between the two regions: (a) the climatic conditions are more severe in the North region in terms of precipitation and temperature conditions; (b) all things, including traffic loadings, pavement age, type and thickness, being equal, pavement condition

deteriorates more rapidly in the North than in the South region. The pavement condition may be expressed either in PSI (pavement serviceability index), or roughness, or PSI-ESAL (equivalent single-axle load loss) [2]. In the light of these differences in climate and pavement performances between the two regions, it appears logical to expect maintenance activity suspension periods to be longer in the South. This is based on the reasoning that in a relatively mild and favorable environmental condition, a pavement distress may be left unattended for a longer period of time, without significantly impairing the overall level of service of the pavement. The results of the present study on maintenance activity suspension study therefore reaffirms the findings of past research studies.

2.4 Chapter Summary

This chapter described a survey conducted in Summer, 1987 to gather additional information required for an optimization programming analysis of routine maintenance in Indiana. Specifically, the objective was to determine for the North and South regions of Indiana the following information: (a) the priority ratings of various routine maintenance activities; and (b) the influence of rehabilitation constraint on routine maintenance scheduling by specifying maintenance activity suspension periods. The survey was successfully conducted and the required information for 14 routine maintenance activities was collected. Priority ratings and suspension periods for all routine maintenance activities by highway class and road condition were presented.

Since the survey data collected were informative, additional analyses were performed to provide further insight into the field maintenance practice in Indiana. The findings obtained are summarized below:

1. The overall priority ratings from the North and South regions showed a fair degree of agreement. Both assigned highest priorities to pavement-related activities on Interstate and high traffic volume OSH, and lowest priorities to activities on low traffic volume OSH with low distress severity level.

2. The South region maintenance personnel placed much more emphasis on drainage-related activities compared to their northern counterpart. The two groups showed excellent agreement on the relative priorities of all other maintenance activities.

3. The difference in the priority ratings between the two regions is believed to be related to the differences in their climatic and topographical conditions. One would therefore expect variations in priority ratings of maintenance activities among regions with different climate and topographic conditions.

4. The partitioning technique with the two-stage survey procedure was found to be effective. The process was easily understood and easily implemented by maintenance personnel with different levels of knowledge and experience.

5. The suspension periods of different maintenance activities differed greatly over a range of 1 day for shallow patching of severe distress on Interstate to more than 300 days for sand seal on OSH with low traffic volume.

6. Considering highway class, Interstate had the shortest suspension

period, and OSH with low traffic volume had the longest. In terms of distress condition, the `severe´ category was given the shortest suspension period, followed by the `medium´ and slight in the order of increasing suspension period length.

7. Sand seal, full width shoulder seal and reconditioning of unpaved shoulders had the longest suspension period, and hence most affected by rehabilitation constraints. On the other hand, shallow patching, deep patching and spot shoulder repairs had the shortest suspension periods and were least affected by rehabilitation schedule.

8. A fair degree of agreement in terms of statistical correlation was found between the suspension period estimates from the North and South region maintenance personnel.

9. The suspension period estimates of the North region were found to be shorter than those of the South region. The difference is significant at 99% confidence level. The severe climatic conditions and the more rapid deterioration rate of pavements in the North region are likely reasons contributing to the difference.

10. Similar to the case of maintenance activity priority ratings, the suspension period of a given maintenance activity is expected to vary with the climatic conditions and pavement deterioration characteristics of the region considered.

CHAPTER 3

DEVELOPMENT OF THE OPTIMIZATION MODEL FOR ROUTINE MAINTENANCE PROGRAMMING

3.1 Background

The existing Indiana highway maintenance management system has three basic management levels, namely the central office level, district level, and subdistrict level. Each subdistrict is further subdivided into two to four maintenance units that are directly responsible for performing maintenance work in the field.

Annual maintenance work programs for the entire state are developed at the central office level. Separate programs are prepared for each district and subdistrict based on their respective maintenance inventory data. These work programs identify the types and total amounts of work to be performed during the following fiscal year. Annual maintenance budgets are then computed from these annual maintenance work programs.

The workload for each maintenance activity is computed from quantity standards that are established largely by engineering judgment and past experience [9]. It should also be noted that the workloads so determined are estimated average annual quantities of total work needed to attain a desired uniform level of service statewide. They do not reflect the needs of a system or class of roads having similar characteristics.

To identify road sections that require maintenance, subdistrict unit foremen are to inspect roads periodically for maintenance needs and record in a Maintenance Needed Report [8]. Based on the record of Maintenance Needed

Reports, subdistrict general foremen would prepare a semi-monthly work schedule for each maintenance unit.

The assignment of routine maintenance activities for the Semi-Monthly Schedule is an area where improvements can be made. Instead of relying on experience and subjective judgment in preparing the schedule, an optimization programming procedure can be incorporated and used to select the best combination of routine maintenance activities. Beside enhancing effective and efficient utilization of resources, the use of optimization programming procedure could help to ensure uniformity and consistency in developing the Semi-Monthly Schedule.

3.2 Formulation of Proposed Model

Six forms of constraints are considered in the model. They are production requirements, budget constraints, manpower availability, equipment availability, material availability, and rehabilitation schedule constraint. The mathematical model is presented below. This is followed by a discussion of the basis and rationale of the formulation.

3.2.1 Integer Programming Model

$$\text{Maximize} \quad \sum_{i=1}^{N_1} \sum_{j=1}^{N_2} \sum_{k=1}^{N_3} W_{ijk} F_{ijk} \tag{3.1}$$

where, W_{ijk} is an integer for $i=1,2,...N_1$, $j=1,2,..$ N_2 and $k=1,2,...,$ N_3.

Subject to

(a) Production requirements

$$0 < W_{ijk} < \frac{T_{ijk}\ Y_{ijk}}{U_{ijk}} \qquad i=1,2,\ldots,N_1 \quad j=1,2,\ldots,N_2 \quad k=1,2,\ldots,N_3 \qquad (3.2)$$

(b) Budget constraint

$$\sum_{i=1}^{N_1} \sum_{j=1}^{N_2} \sum_{k=1}^{N_3} W_{ijk}\ U_{ijk}\ C_{ijk} < B \qquad (3.3)$$

(c) Manpower availability

$$\sum_{i=1}^{N_1} \sum_{j=1}^{N_2} \sum_{k=1}^{N_3} W_{ijk}\ h_j < H \qquad = 1,2,\ldots,L \qquad (3.4)$$

(d) Equipment availability

$$\sum_{i=1}^{N_1} \sum_{j=1}^{N_2} \sum_{k=1}^{N_3} W_{ijk}\ q_{jr} < Q_r \qquad r = 1,2,\ldots,R \qquad (3.5)$$

(e) Material availability

$$\sum_{i=1}^{N_1} \sum_{j=1}^{N_2} \sum_{k=1}^{N_3} W_{ijk}\, m_{js} \leq M_s \qquad s = 1,2,\ldots,S \tag{3.6}$$

(f) Rehabilitation constraints

$$\gamma_{ijk} = \frac{D - d_{ijk}}{D} \qquad i=1,2,\ldots,N_1 \quad j=1,2,\ldots,N_2 \quad k=1,2,\ldots,N_3 \tag{3.7}$$

where, W_{ijk} = equivalent workload units in number of work-days of routine maintenance activity j on highway i with distress severity level k,

F_{ijk} = priority weighting factor for routine maintenance activity j of distress severity level k on highway i,

N_1 = total number of highways considered,

N_2 = total number of routine maintenance activities considered,

N_3 = total number of distress severity levels considered,

T_{ijk} = total workload of routine maintenance needs in work measurement units (see Table 3.1) for routine maintenance activity j on highway i with distress severity level k,

γ_{ijk} = rehabilitation constraint factor for routine maintenance activity j on highway i with distress severity level k, $0 \leq \gamma_{ijk} \leq 1$,

U_{ijk} = work productivity for routine maintenance activity j on highway i with distress severity level k,

C_{ijk} = cost per production unit of routine maintenance activity j on highway i with distress severity level k,

B = total budget amount allocated for the analysis period considered,

h_j = number of man-days of maintenance crew type required for each production day of routine maintenance activity j,

H = total available number of man-days of maintenance crew type ,

L = total number of maintenance crew types,

q_{jr} = number of equipment-days of equipment type r required for each production day of routine maintenance activity j,

Q_r = total available number of equipment-days of equipment type r,

R = total number of equipment types,

m_{js} = quantity of material type s required for each production day of routine maintenance activity j,

M_s = total available quantity of material type s,

S = total number of material types,

d_{ijk} = interference period in number of working days during which no maintenance activity type j would be performed on highway i with distress severity level k,

D = total number of work-days in analysis period.

3.2.2 Objective Function

The objective function in Equation (3.1) is the sum of equivalent work-day units of routine maintenance activities each weighted by an appropriate priority factor. Work quantities of routine maintenance activities are generally expressed by their respective work measurement units as illustrated in Table 3.1. It is necessary to convert these work quantity measurements into a common basis of reference. Equivalent work-day is chosen because routine maintenance tasks are typically assigned to field crews on a daily basis. In the Indiana maintenance management system, such tasks are authorized daily at subdistrict level by general or unit foreman to each crew with crew day cards [8]. There is one card per crew per activity. Each card contains information on what is to be done, when, how, and the manpower and equipment assigned. Expressing work quantity of a routine maintenance type by equivalent work-days

Table 3.1 Work Measurement Units of Some Routine Maintenance Activities in Indiana

Activity Code	Activity Type	Work Measurement Unit
201	Shallow Patching	Tons of Premix
202	Deep Patching	Tons of Premix
203	Premix Leveling	Tons of Premix
204	Full Width Shoulder Seal	Foot Miles
205	Seal Coating	Lane Miles
206	Sealing Longitudinal Cracks & Joints	Linear Miles
207	Sealing Cracks	Lane Miles
210	Spot Repair of Unpaved Shoulders	Tons of Aggregates
211	Blading Shoulders	Shoulder Miles
212	Clipping Unpaved Shoulders	Shoulder Miles
213	Reconditioning Unpaved Shoulders	Shoulder Miles
231	Clean & Reshape Ditches	Linear Feet
234	Motor Patrol Ditching	Ditch Miles

therefore has a direct practical meaning easily understood by both field and planning personnel.

Another good reason for using equivalent work-days is that the performance standards of Indiana maintenance management system are all expressed in terms of daily production rate. There is hence a well-defined relationship between amounts of workload and equivalent work-days:

$$P_{ijk} = W_{ijk}\ U_{ijk} \qquad i=1,2,\ldots,N_1 \quad j=1,2,\ldots,N_2 \quad k=1,2,\ldots,N_3 \qquad (3.8)$$

where, P_{ijk} = amount of workload for routine maintenance activity type j on highway i with pavement distress severity level k, expressed in appropriate work measurement unit specified in Table 3.1.

W_{ijk} and U_{ijk} are as defined in Equations (3.1) and (3.2).

Multiplied to each term of the decision variables, W_{ijk}, in Equation (3.1) is a priority weighting factor F_{ijk}. Each routine maintenance activity is identified by activity type, distress severity level, and highway type. All things being equal, sections with a higher severity of distresses tend to require maintenance more urgently, and vice versa. The need for the detailed identification of routine maintenance activity is apparent because each combination of activity type - distress severity - highway type has a different priority ranking in the importance to maintain and preserve the overall state of network highway conditions. An activity with a higher priority ranking will be assigned a bigger value of weighting factor in Equation (3.1).

It is significant to note that the maximization process of the integer programming procedure would move in the direction of selecting higher priority

activities first. Since priority weighting factors reflect relative importance in maintaining overall state of highway conditions, the integer programming solution would therefore provide the best selection of maintenance activities for highway condition preservation. The objective function in Equation (1) can thus be viewed as a measure of effectiveness of routine maintenance strategy. A poor selection of low priority maintenance activities, leading to a low objective function value, would not be effective in preserving highway conditions, and vice versa.

3.2.3 Production Requirements

These production constraints simply state that the amount of maintenance work assigned for each activity type should not exceed the need for it. This is logical because any maintenance work done beyond what is necessary would not be effective. Better return could be achieved by spending the resources on other needy activities. Since the decision variables W_{ijk} cannot take on negative values, non-negativity constraints are also included in the production requirement constraints. The rehabilitation factor, γ_{ijk}, will be discussed under the heading of rehabilitation constraint.

3.2.4 Resource Constraints

Equations (3.3) though (3.6) specify constraints on resources including funding, manpower, equipment and material. It is noted that the existing maintenance management practice in Indiana allocates annual budget amounts to management units by routine maintenance activity types based primarily on pre-established quantity standards [9]. To account for these fund allocation constraints, Equation (3.3) should be modified as follows:

$$\sum_{j=1}^{N_2} \sum_{i=1}^{N_1} \sum_{k=1}^{N_3} W_{ijk} U_{ijk} C_{ijk} \leq B \tag{3.9}$$

where, B = budgeted fund for routine maintenance during the analysis period.

The amount of budge available, B, during an analysis period less than a year can be estimated on the basis of historical records. Also, the budget constraints can be set by activity type, if the information is available.

3.2.5 Rehabilitation Constraints

Effective coordination between routine maintenance programming and scheduling of rehabilitation activities, such as resurfacing and reconstruction, is essential for a successful highway management system. Lack of coordination between the two forms of operations has been identified as a problem [3,19]. Rehabilitation constraints are included in the formulation in this study to ensure proper coordination between the two operations.

The constraint factors γ_{ijk} in Equations (3.2) and (3.7) each represents the proportion of maintenance needs of a routine maintenance activity required to be satisfied after taking into consideration the constraints imposed by rehabilitation work. Figure 3.1 shows schematically how the correction factor for an individual highway section would be computed.

Values of γ_{ijk} may vary from highway type to highway type, depending on their structural and material characteristics, volumes of traffic carried, and highway classification. They may also be different for different routine maintenance activity types. For instance, seal coating would probably not be scheduled within 1-3 years preceding a major resurfacing work. On the other

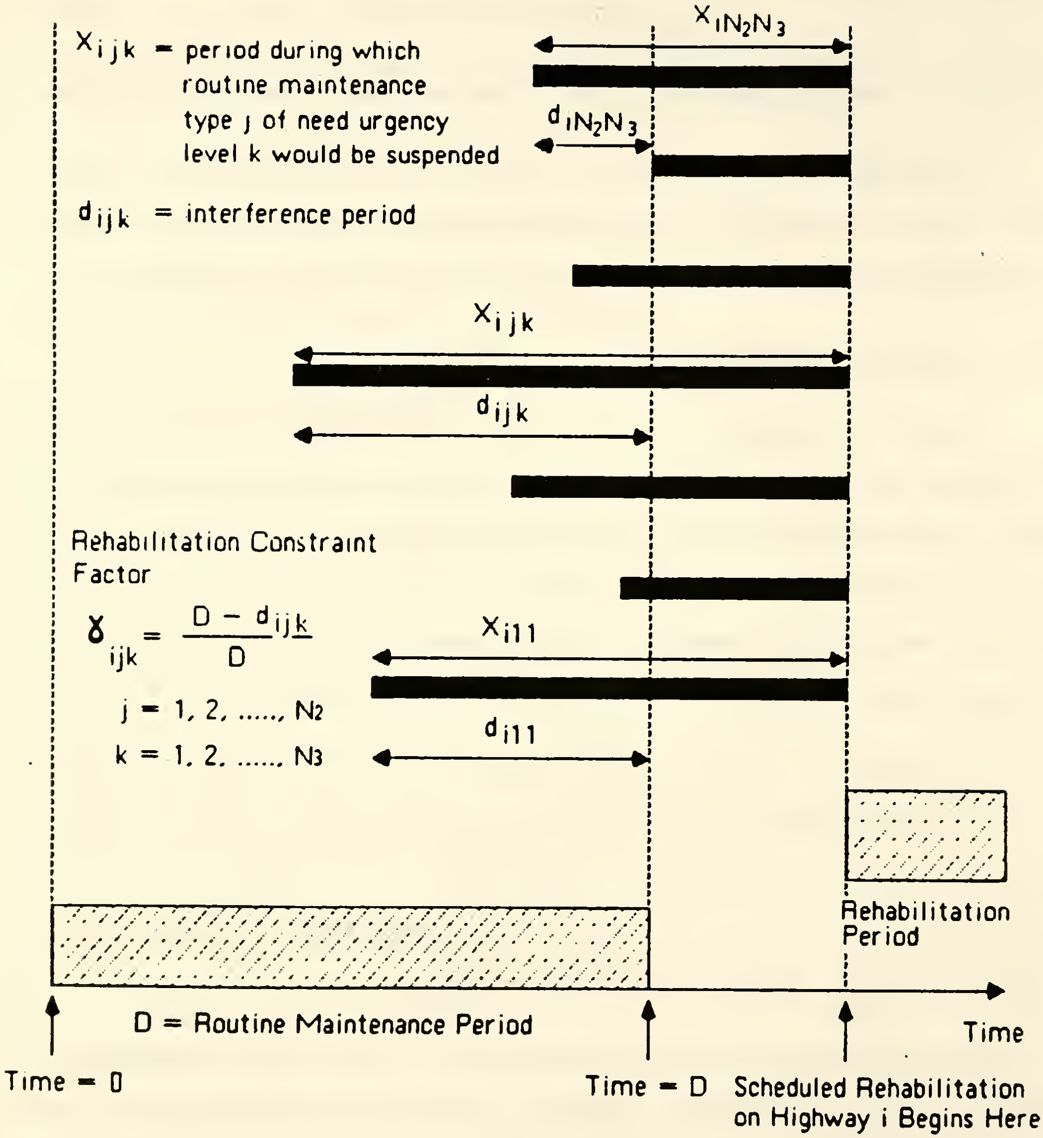


Figure 3.1 Computation of Rehabilitation Constraint Factor γ_{ijk} for Highway Section i

hand, shallow patching work may be required weeks or even days before a scheduled rehabilitation to maintain adequate level of service to the traveling public before the rehabilitation work. Similarly, owing to cost-effectiveness, safety and level of service considerations, the distress severity level of a highway element would also have an influence on the length of interference period d_{ijk}, and hence, the value of γ_{ijk}.

Instead of individual highway sections, the programming model can also be applied to highways grouped under some highway classes or types. In that case, the rehabilitation constraint factor γ_{ijk} is computed preferably by equivalent work-day units and Equation (3.7) should be replaced by:

$$\gamma_{ijk} = \frac{T_{ijk} - \Sigma(T_{ijk})_d}{T_{ijk}} \qquad i=1,2,\ldots,N_1 \quad j=1,2,\ldots,N_2 \quad k=1,2,\ldots,N_3 \tag{3.10}$$

where the term $\Sigma(T_{ijk})_d$ refers to the maintenance workload associated with the interference periods (Figure 3.1) of all the highway sections in highway class i. A zero value of γ_{ijk} represents a case with $d_{ijk} = D$ where there is a complete interference from rehabilitation work. A γ_{ijk} value of unity implies $d_{ijk} = 0$, indicating no interference from rehabilitation.

3.3 Data Requirements

The data required for the model may be classified into the following main categories:

a. Performance standards

b. Unit costs

c. Resource inventory data

d. Maintenance needs assessment

e. Priority ranking of routine maintenance work

f. Schedule of rehabilitation activities

A description of the specific forms of data required in each of the above categories is presented below. Also described are their respective acquisition procedures currently in use or proposed for use in Indiana. A step-by-step guide of input preparation is given in Appendix D.

3.3.1 Performance Standards

Performance standards define the way in which each routine maintenance activity should be performed. They provide guidance to the planning, supervisory and field personnel in the following areas: (i) size and composition of field crew, (ii) number of units and types of equipment, (iii) types and amounts of materials, (iv) step by step procedures for performing the work, and (v) expected daily production.

Specifically, performance standards provide input information for the following coefficients in the routine maintenance programming model: U_{ijk} in Equation (3.3), h_j in Equation (3.4), q_{jr} in Equation (3.5), and m_{js} in Equation (3.6). Performance standards used in the maintenance management of Indiana are found in IDOH Field Operations Handbook [8].

The proposed programming model requires information on daily production rate, U_{ijk}, by road condition. Such information is not available in the Indiana maintenance performance standards. However, an earlier phase of the

present study specifically developed average daily production data that are suitable for use in the model. This work was documented in Reference [7] where daily production data of various routine maintenance activities for different roadway conditions can be found.

3.3.2 Unit Cost Data

Unit cost, expressed as cost per unit production for each routine maintenance activity is required. More desirably, as shown by the coefficient C_{ijk} in Equation (3.3), cost data by routine maintenance activity type for different roadway conditions should be available. Such detailed cost information would greatly enhance the usefulness of the proposed programming model.

A large amount of research has been undertaken in recent years at Purdue University on routine maintenance costs in Indiana [3,4,7,16]. Because of this prior research, it is possible to obtain a unit cost per production unit of each activity for different roadway conditions as required by Equation (3.3) of the programming model.

3.3.3 Resource Inventory Data

Available resources such as budget funding, manpower, equipment and materials are necessary input information to the proposed programming model. Budget, manpower and equipment data are easily obtainable from the District or Subdistrict offices of IDOH. Information on material availability is however not as clear.

The requirements for major materials are usually calculated according to routine maintenance work performance, and purchase orders are made for "the

right kinds and quantities of materials at the right time to make sure they are available when required" [9]. It therefore appears appropriate to assume that material availability constraints would not be the governing factor in the programming analysis. Consequently, the budget constraint in Equation (3.3) was appropriately adjusted to exclude the amount of material costs.

3.3.4 Maintenance Needs Assessment

The amounts of maintenance need by highway section or highway class and by activity type form the upper bound constraints to the decision variables W_{ijk} in Equation (3.2). The current practice of formulating maintenance workload needs in Indiana relies on quantity standards that were established largely from past experience and engineering judgment. The quantity standards enable workload need of each subdistrict to be computed according to its available inventory units. Quantity standards are currently available for each routine maintenance activity by two highway classes, Interstate and Other State Highways.

In the first phase of the present study, Montenegro and Sinha [6] developed a system of assessing highway routine maintenance needs based on a condition aurvey of roadways by unit foremen at the subdistrict level. This system would provide maintenance personnel at district and subdistrict levels with realistically defined maintenance needs data. It identifies maintenance needs by highway route, routine maintenance activity type, and distress severity level. These maintenance needs data could readily be input into the programming model proposed in this study.

3.3.5 Priority Ranking of Routine Maintenance Work

The significance of the priority weighting factors, F_{ijk}, in Equation

(3.1) has been discussed in an earlier section where the formulation of the objective function was explained. Equation (1) requires that all the routine maintenance work items, a total of $(N_1 \times N_2 \times N_3)$ in number, be ranked by their relative importance in contributing towards preserving the overall network highway conditions. In the survey of subdistrict field personnel and District Engineers [14] described in Chapter 2, a two-stage procedure for ranking and determining priority scores, was adopted for both highway class and condition level combinations and the routine maintenance activity types. Items were ranked first followed by assignment of priority scores and the final priority score for an activity type-distress severity level-highway class combination is given by Equation (3.11) below:

$$F_{ijk} = (f_1)_{ik} \times (f_2)_j \tag{3.11}$$

where, F_{ijk} = priority weighting factor defined in Equation (3.1)

$(f_1)_{ik}$ = routine maintenance priority score for combination of highway class i and distress severity level k in relation to all other combinations of the two elements

$(f_2)_j$ = routine maintenance priority score for routine maintenance activity type j in relation to all other routine maintenance activity types.

It should be mentioned that absolute values of F_{ijk} factors have no direct effect on the solution of decision variables W_{ijk} in Equation (3.1). It is their relative magnitudes or ranks that makes the difference.

3.3.6 Schedules of Rehabilitation Activities

Lack of coordination between routine maintenance and rehabilitation

operations usually arises because the philosophy behind scheduling of major rehabilitation activities is different from that for routine maintenance programming. The long term and predictive nature of the data required for rehabilitation planning does not provide enough information to the routine maintenance personnel.

Since effective coordination between the two forms of operation could result in substantial savings in both, it is desirable to have a routine maintenance data base that contains schedule information of relevant rehabilitation activities. A data base system of this nature has been proposed for Indiana highways in an earlier phase of the present study [20]. Such a system would provide the necessary information for the rehabilitation constraints in Equations (3.7) and (3.10).

3.4 Numerical Illustrative Example

Presented in this section is a numerical example based on a hypothetical problem. However, the input data were obtained from the Indiana Department of Highways. For illustration purpose, four highway classes, four routine maintenance activity types and three levels of distress severity were considered. Tables 3.2 through 3.7 describe the necessary input data to the problem. Material availability constraints, as explained earlier, were assumed to be satisfied and hence not included.

The solution to the problem is shown in Table 3.8(a) where the value of each decision variable W_{ijk} is given. It was solved using the branch and bound algorithm of MPOS [15]. The optimal workload quantity selected for each

Table 3.2 Daily Production Rate Data.

Distress Severity Level, k	Maintenance Activity Type, j			
	j=1 (Code 201)	j=2 (Code 202)	j=3 (Code 203)	j=4 (Code 206)
Severe (k=1)	7.2	19.8	120.0	6.3
Moderate (k=2)	4.2	10.4	88.6	8.4
Slight (k=3)	2.8	6.8	55.0	10.2

Note: 1. Description and production measurement unit of each maintenance activity type are given in Table 3.1.

2. Values in the table represent U_{ijk} in Equation (3.2) in appropriate measurement units.

3. U_{ijk} values for given indices of j and k are constant regardless highway class i.

Table 3.3 Unit Cost Data.

Distress Severity Level, k	Maintenance Activity Type, j			
	j=1 (Code 201)	j=2 (Code 202)	j=3 (Code 203)	j=4 (Code 206)
Severe (k=1)	85.2	77.4	36.3	131.0
Moderate (k=2)	119.0	121.0	38.1	113.0
Slight (k=3)	159.0	165.0	42.4	103.0

Note: 1. Description and production measurement unit of each maintenance activity type are given in Table 3.1.

2. Values in table represent C_{ijk} in Equation (3.3) in dollars per production measurement unit.

3. C_{ijk} values for given indices of j and k are constant regardless of highway class i.

Table 3.4 Manpower and Equipment Requirements.

Maintenance Activity, j	Manpower Requirement, $h_{j\ell}$				Equipment Requirement, q_{jr}					
	ℓ=1	ℓ=2	ℓ=3	ℓ=4	r=1	r=2	r=3	r=4	r=5	r=6
j=1	0	2	4	0	1	0	1	0	0	0
j=2	1	1	5	1	1	1	0	0	0	1
j=3	1	3	5	2	3	1	1	1	0	1
j=4	1	2	2	4	2	1	0	1	0	0

Note: 1. Manpower and equipment requirement values are in man-days and equipment-days respectively

2. Manpower types 1 to 4 represent respectively supervisors, drivers, laborers and equipment operators

3. Equipment types 1 to 6 represent respectively dump trucks, pickup trucks, crew cabs, distributors, loaders and rollers.

Table 3.5 Maintenance Priority Weighting Factors.

Highway Class, i	Distress Severity Level, k	Maintenance Activity Type, j			
		j=1	j=2	j=3	j=4
i=1 (Urban Interstate)	k=1 (Severe)	90	100	70	50
	k=2 (Moderate)	63	90	63	45
	k=3 (Slight)	54	60	42	30
i=2 (Urban Arterial)	k=1 (Severe)	72	80	56	40
	k=2 (Moderate)	54	70	49	35
	k=3 (Slight)	45	50	35	25
i=3 (Rural Interstate)	k=1 (Severe)	76.5	85	59.5	42.5
	k=2 (Moderate)	58.5	75	52.5	37.5
	k=3 (Slight)	40.5	45	31.5	22.5
i=4 (Rural Primary)	k=1 (Severe)	70.5	65	45.5	32.5
	k=2 (Moderate)	36	40	28	20
	k=3 (Slight)	18	20	14	10

Note: Values in the table represent F_{ijk} in Equation (3.1).

Table 3.6 Data on Maintenance Needs and Rehabilitation Constraint Factors.

Highway Class, i	Distress Severity Level, k	Amount of Maintenance Needs				Rehabilitation Constraint Factors			
		Maintenance Activity Type, j				Maintenance Activity Type, j			
		j=1	j=2	j=3	j=4	j=1	j=2	j=3	j=4
i=1 (Urban Interstate)	k=1 (Severe)	4	6	8	2	0.82	0.83	1.00	0.80
	k=2 (Moderate)	6	4	2	3	0.70	0.90	0.90	1.00
	k=3 (Slight)	3	25	13	18	1.00	1.00	1.00	1.00
i=2 (Urban Arterial)	k=1 (Severe)	2	6	9	2	0.93	1.00	1.00	0.92
	k=2 (Moderate)	2	10	8	8	0.84	1.00	1.00	0.96
	k=3 (Slight)	4	20	15	15	0.81	1.00	1.00	0.90
i=3 (Rural Interstate)	k=1 (Severe)	5	8	6	5	0.92	1.00	1.00	0.83
	k=2 (Moderate)	5	2	10	10	0.78	1.00	1.00	0.91
	k=3 (Slight)	5	15	15	10	0.80	1.00	1.00	0.96
i=4 (Rural Primary)	k=1 (Severe)	3	4	8	4	1.00	1.00	1.00	1.00
	k=2 (Moderate)	4	16	12	20	1.00	1.00	1.00	1.00
	k=3 (Slight)	15	15	18	15	1.00	1.00	1.00	1.00

Note: Amounts of maintenance needs are expressed in terms of equivalent work-days, each representing directly the quantity $(\frac{T_{ijk}}{U_{ijk}})$ in Equation (3.2).

Table 3.7 Resource Constraints and Other Input Information.

Item			Value
1.	Analysis period	D	45 working days
2.	Budget allocation	b_1	18,000 dollars
		b_2	20,000 dollars
		b_3	13,000 dollars
		b_4	9,000 dollars
3.	Manpower availability	H_1	90 man-days
		H_2	135 man-days
		H_3	270 man-days
		H_4	90 man-days
4.	Equipment availability	Q_1	135 equipment-days
		Q_2	45 equipment-days
		Q_3	45 equipment-days
		Q_4	45 equipment-days
		Q_5	45 equipment-days
		Q_6	45 equipment-days

Note: Symbols used in table are defined in Equations (3.1) to (3.10).

Table 3.8 Integer Programming Solution to Example Problem.

(a) Output in Equivalent Work-Days

$W_{111} = 3$
$W_{112} = 4$
$W_{113} = 3$
$W_{121} = 4$
$W_{122} = 3$
$W_{132} = 1$

$W_{133} = 4$
$W_{141} = 1$
$W_{142} = 3$
$W_{211} = 1$
$W_{212} = 1$
$W_{213} = 3$

$W_{222} = 6$
$W_{241} = 1$
$W_{311} = 4$
$W_{312} = 3$
$W_{313} = 4$
$W_{322} = 2$

$W_{341} = 4$
$W_{342} = 1$
$W_{411} = 3$
$W_{412} = 4$
$W_{413} = 1$

Note: All other W_{ijk} have values equal to zero.

(b) Workload in Work Measurement Units

W_{111} = 21.6 tons of premix
W_{112} = 16.8 tons of premix
W_{113} = 8.4 tons of premix
W_{121} = 79.2 tons of premix
W_{122} = 31.2 tons of premix
W_{132} = 88.6 tons of premix
W_{133} = 55.0 tons of premix
W_{141} = 6.3 linear miles
W_{142} = 25.2 linear miles
W_{211} = 7.2 tons of premix
W_{212} = 4.2 tons of premix
W_{213} = 8.4 tons of premix

W_{222} = 62.4 tons of premix
W_{241} = 6.3 linear miles
W_{311} = 28.8 tons of premix
W_{312} = 12.6 tons of premix
W_{313} = 11.2 tons of premix
W_{322} = 20.8 tons of premix
W_{341} = 25.2 linear miles
W_{342} = 8.4 linear miles
W_{411} = 21.6 tons of premix
W_{412} = 16.8 tons of premix
W_{413} = 2.8 tons of premix

(c) Workload by Highway Class and Routine Maintenance Activity Type

	Shallow Patching (Tons of Premix)	Deep Patching (Tons of Premix)	Premix Leveling (Tons of Premix)	Seal Long. Cracks (Linear Miles)
Urban Interstate	46.8	110.4	143.6	31.5
Urban Arterial	19.8	62.4	0	6.3
Rural Interstate	52.6	20.8	0	33.6
Rural Primary	41.2	0	0	0

routine maintenance item as given in Table 3.8(b) was computed by multiplying W_{ijk} by its corresponding unit production value, U_{ijk}. Table 3.8(c) presents the results by highway class and routine maintenance activity type.

The most dominating influence on the final solution appears to come from priority weighting factors. Urban and rural Interstates received most maintenance because of their high priority rankings. The same holds true for shallow and deep patching when routine maintenance activities are compared. These results are within expectation because priority weighting factors directly reflect the sequence in which routine maintenance needs should be carried out. This desired sequence would only be affected to some extent by resource availability and other constraints.

CHAPTER 4

SUMMARY AND CONCLUSIONS

The results presented in this interim report provide a summary of the assessment of ranking and priority scores of the fourteen routine maintenance activities by IDOH field personnel. An optimization model for routine maintenance programming in Indiana has also been presented.

4.1 Routine Maintenance Activity Priority Ratings

A summary of the priority ratings for routine maintenance activities perceived by IDOH field personnel (District and/or Field Engineers, Superintendents and Unit Foremen) has been provided in Chapter 2. An indication has been given of the relative priority scores for Interstates as well as High Volume (> 400 vpd) and Low Volume (Less than 400 vpd) Other State Highways. Also, similar priority scores have been determined for the fourteen IDOH routine maintenance activities (201, 202, 203, 204, 205, 206, 207, 208, 210, 211, 212, 213, 231 and 234).

A procedure for computing the final priority ratings for routine maintenance activities by highway class and distress severity level is described. The final priority ratings thus obtained can be used directly as weighting factor input to a routine maintenance optimization programming model such as the one described in this report. Also, included in Chapter 2 are analyses performed on the survey data collected, with an aim of demonstrating how other useful information on routine maintenance practice could be derived from the data.

4.2 Rehabilitation Constraints

The need to coordinate rehabilitation and routine maintenance activities in the planning of highway maintenance is highlighted. To express the rehabilitation constraints on routine maintenance planning, the concept of interference suspension periods for routine maintenance activities was introduced. A suspension period of a routine maintenance activity is a period prior to a rehabilitation work during which the particular routine maintenance activity would not be carried out. An interference period is the duration within a routine maintenance program period that the routine maintenance activity would not be carried out. A routine maintenance operation suspension period was also defined to relate the two parameters defined above. The basic parameter to determine from the survey was the suspension period for each maintenance activity by highway class and distress severity level.

The survey was successfully conducted to furnish the desired information on maintenance activity suspension periods. These data are required in a routine maintenance optimization programming model to incorporate quantitatively the influence of rehabilitation constraints on routine maintenance planning. As in the case of priority ratings study, additional analyses were conducted on the data obtained to provide further insight into the routine maintenance practice in Indiana.

4.3 The Optimization Model for Routine Maintenance Programming

Mathematical programming is currently not used in selecting routine maintenance activities by the Indiana maintenance management system. Hence, an integer programming model was developed to arrive at an optimal combination

of routine maintenance activities for achieving the goal of preserving highway systems under a given set of constraints. The constraints considered included maintenance need requirements, budget allocation, manpower, material and equipment availability, and pavement rehabilitation schedule. A priority weighting factor is assigned to each maintenance work so that higher priority work would be selected for execution. The assignment of priority weighting factors takes into consideration (i) the relative importance of each routine maintenance activity in preserving highway systems at a desired level of service condition, (ii) the urgency of need for a maintenance work by severity of distresses, and (iii) the type of highway section or highway class.

A considerable amount of routine maintenance data is required for a routine maintenance programming analysis to produce useful results. The importance of setting up a good routine maintenance data base is stressed. Discussed are the types and forms of data needed and the ways in which such data are acquired and processed in Indiana. A numerical example illustrates the procedure of data computation involved in a routine maintenance programming analysis using the proposed model. The proposed programming procedure has great potential in further enhancing the efficiency and effectiveness of the existing maintenance management system in Indiana. With some minor modifications, it should also find useful applications in other similar maintenance management systems.

4.4 Applications of the Proposed Optimization Model

The proposed programming model was developed particularly for application at subdistrict levels in Indiana. A step-by-step guide to using the proposed model is included in Appendix D. The applicability and usefulness of such a model can be recognized by examining its potential impact on the maintenance management system in Indiana.

1. The current bi-monthly selection of routine maintenance activities can be enhanced by the proposed programming procedure without making any changes in the existing management structure. The proposed procedure is able to formulate a program for a more effective and economical utilization of resources.

2. Adoption of the proposed procedure will help to eliminate non-uniform and inconsistent decision-making which is inevitable with the present routine maintenance programming procedure. By promoting uniformity and consistency across the state at the subdistrict level, it will greatly help planning, monitoring and evaluation of routine maintenance performance on a statewide basis.

3. The model can be easily expanded and modified for use at other network levels. Also, program periods other than the two-week period currently used in Indiana can be analyzed to provide longer-term information that may be useful for planning purposes.

4. Shortfalls and surpluses of resources can be analyzed using the proposed programming model. The possible benefits of re-allocating resources can

be investigated by performing parameter sensitivity analysis. These analyses are useful because some parameters might have been set as a result of managerial policy decisions, and these decisions could be reviewed after examining their consequences on what can be achieved. The amount of resources to be made available to a given activity may be adjusted to achieve better results. For instance, the number of temporary laborers to be hired over a given period of the year could be determined by such analyses.

An extensive amount of data is needed for successful application of the proposed model. All these data, however, should be already available in a fully operational maintenance management system. The value and usefulness of the output information depend much on the accuracy and exhaustiveness of the acquired data. The establishment of an appropriate routine maintenance data base is an essential prerequisite to a successful routine maintenance programming analysis.

Finally, it is appropriate to mention that the development of a highway maintenance management system is a non-ending process. The same apply to the data base of the proposed optimization model. Users of the optimization model would have to update continually input data on cost, production, manpower and equipment requirements, as well as data on maintenance activity priority ratings and suspension periods. This continuing updating effort is essential for a meaningful application of the model.

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APPENDIX A

Histogram Presentation of Survey Data on Ranking and Priority Scores

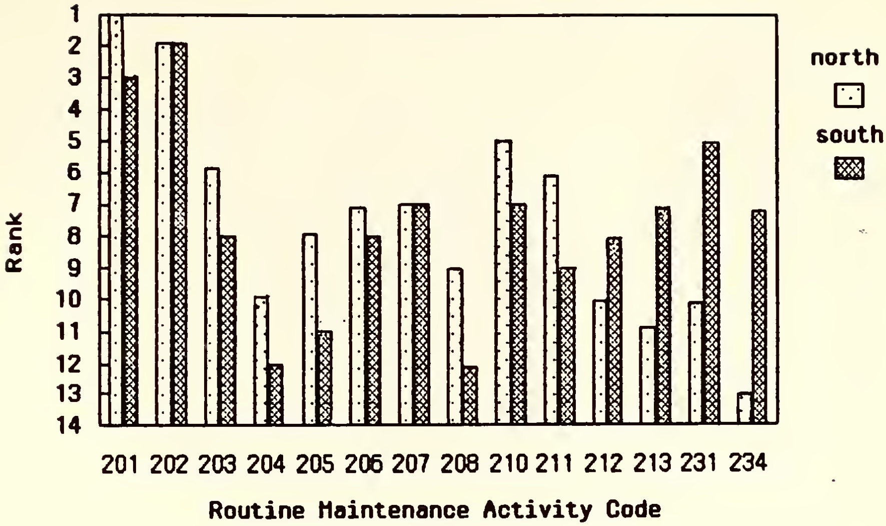

Figure A.1 Ranks of Various Highway Maintenance Activities.

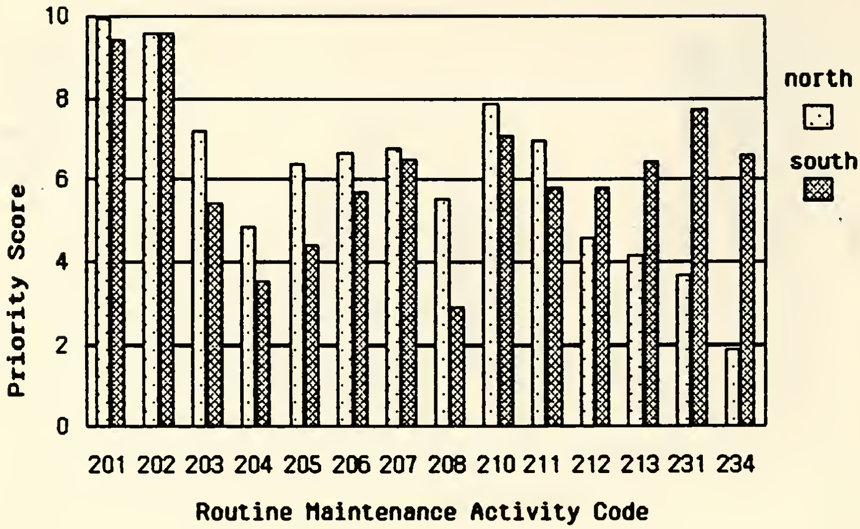

Figure A.2 Priority Scores of Various Highway Maintenance Activities.

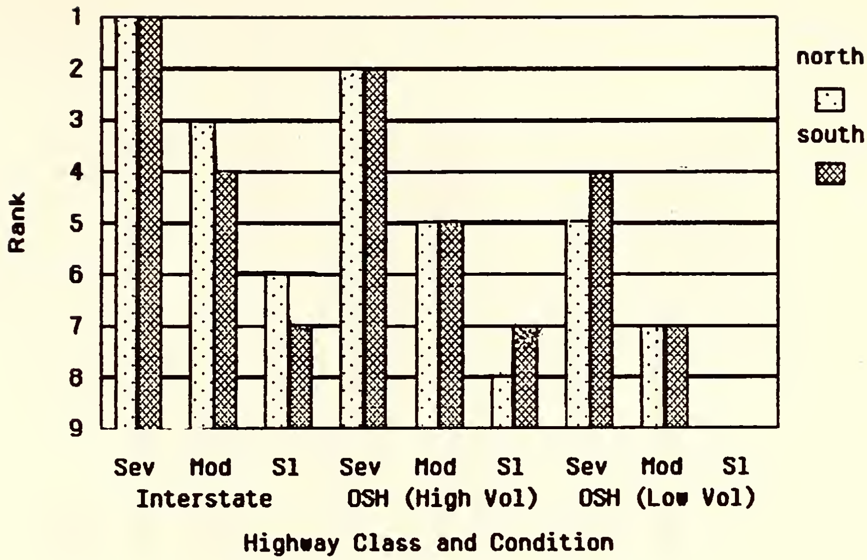

Figure A.3 Ranks of Highway Class and Condition.

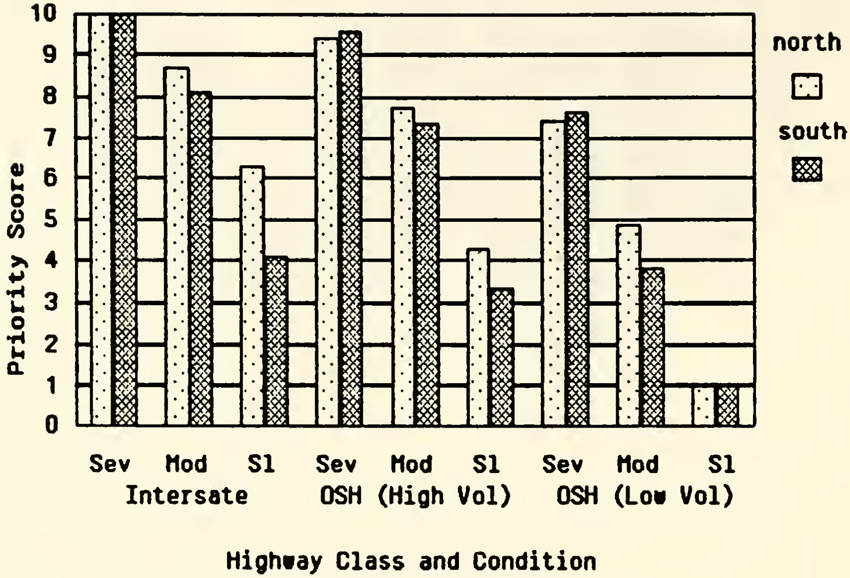

Figure A.4 Priority Scores of Highway Class and Condition.

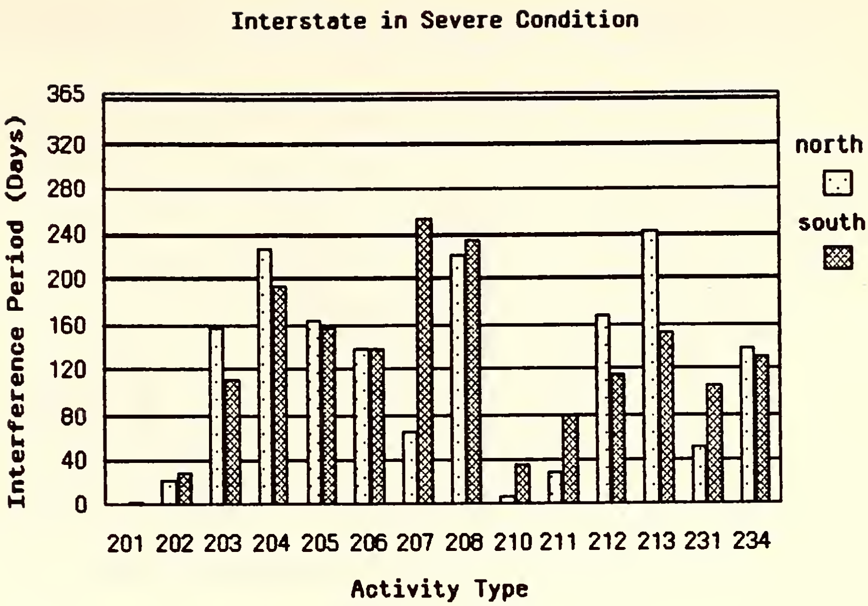

Figure A.5 Activity Interference Periods for Interstates in Severe Condition.

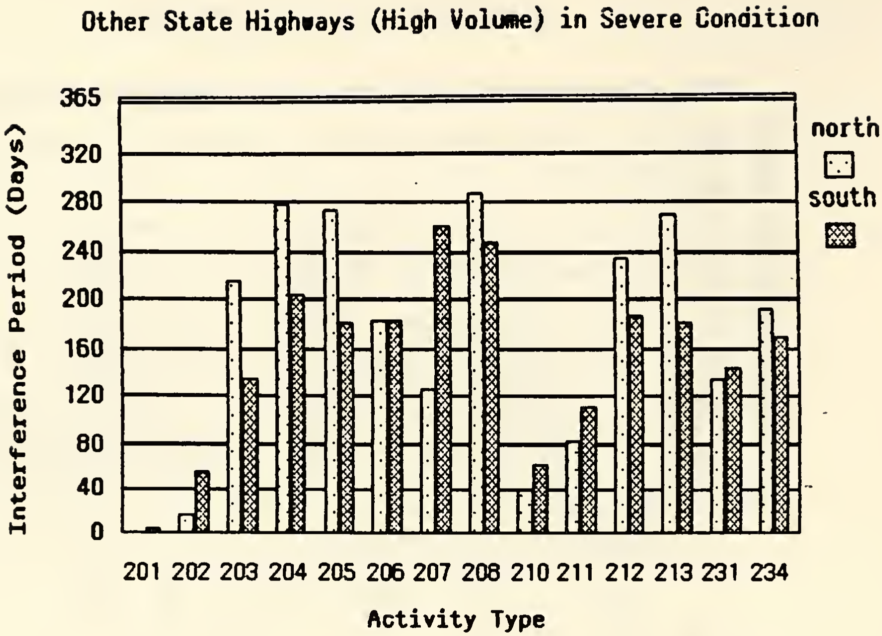

Figure A.6 Activity Interference Periods for High-Volume OSH in Severe Condition.

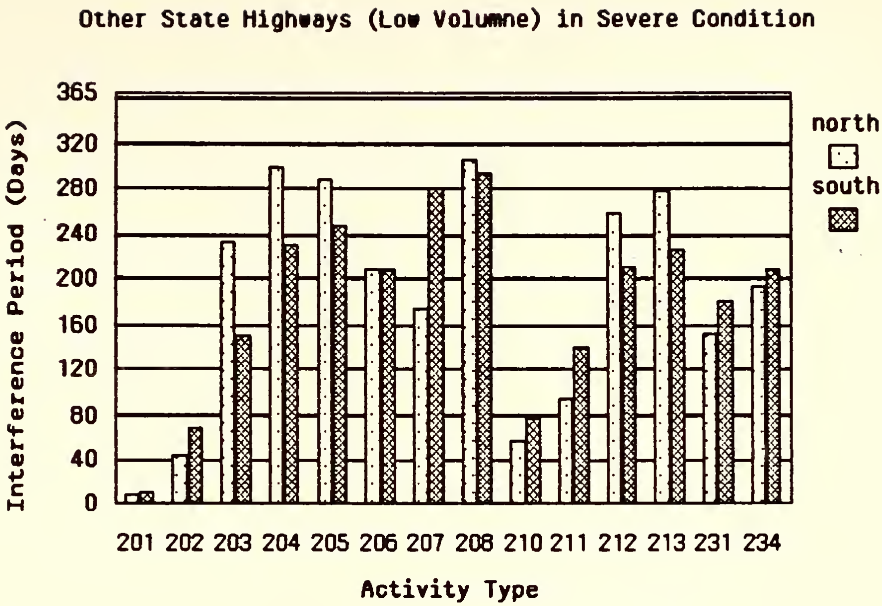

Figure A.7 Activity Interference Periods for Low-Volume OSH in Severe Condition.

APPENDIX B

Histogram Presentation of Survey Data on Routine Maintenance Activity Suspension Period

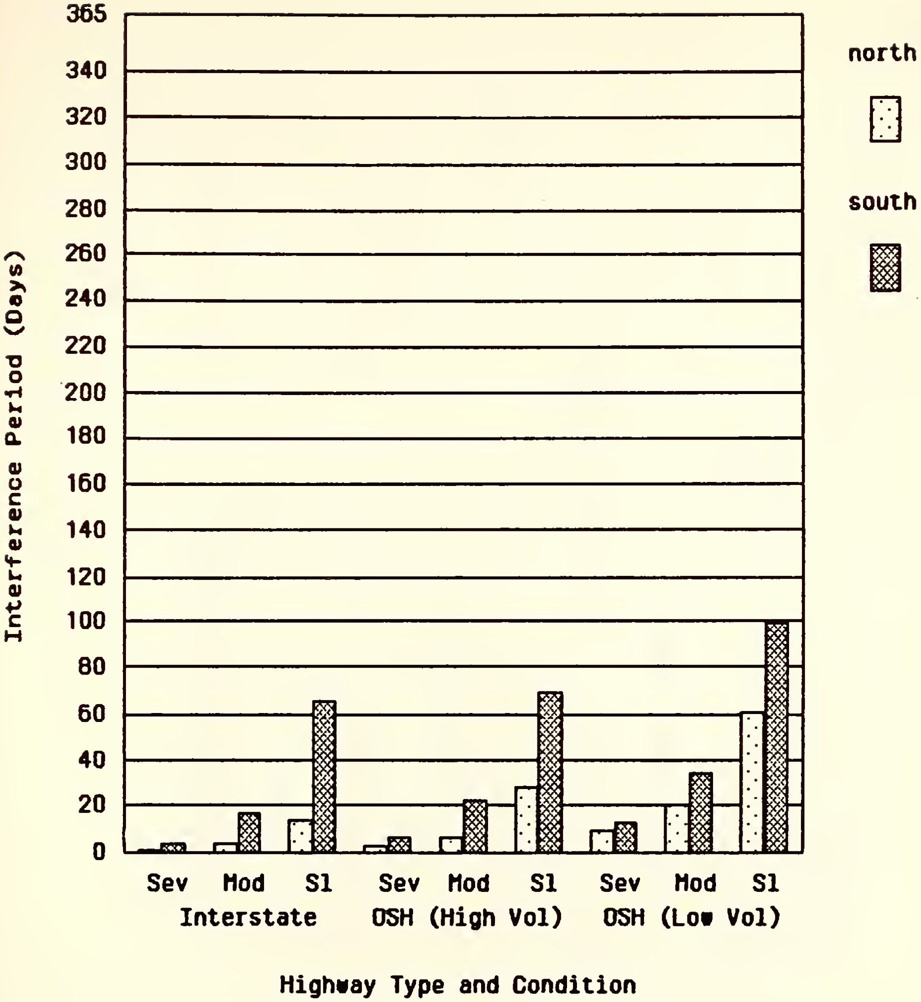

Figure B.1 Resurfacing Constraints for Shallow Patching (201).

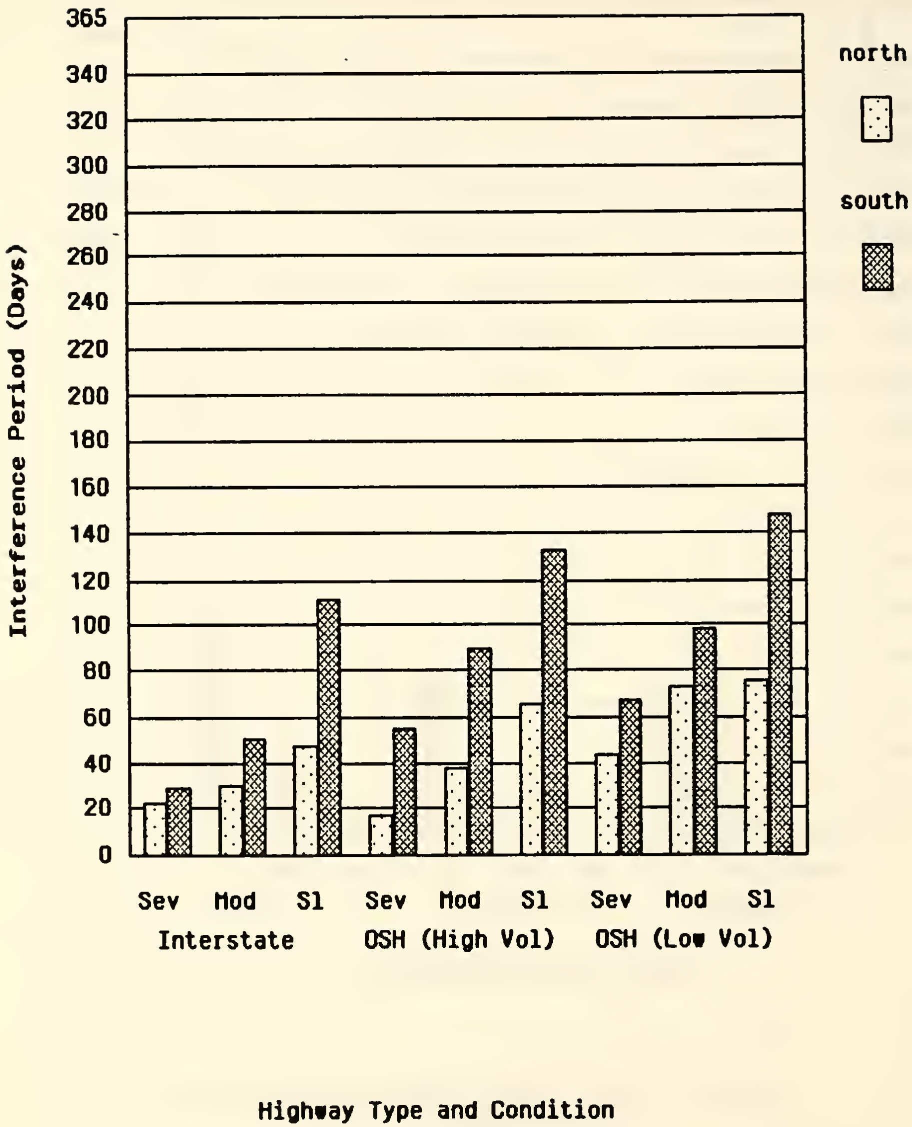

Figure B.2 Resurfacing Constraints for Deep Patching (202).

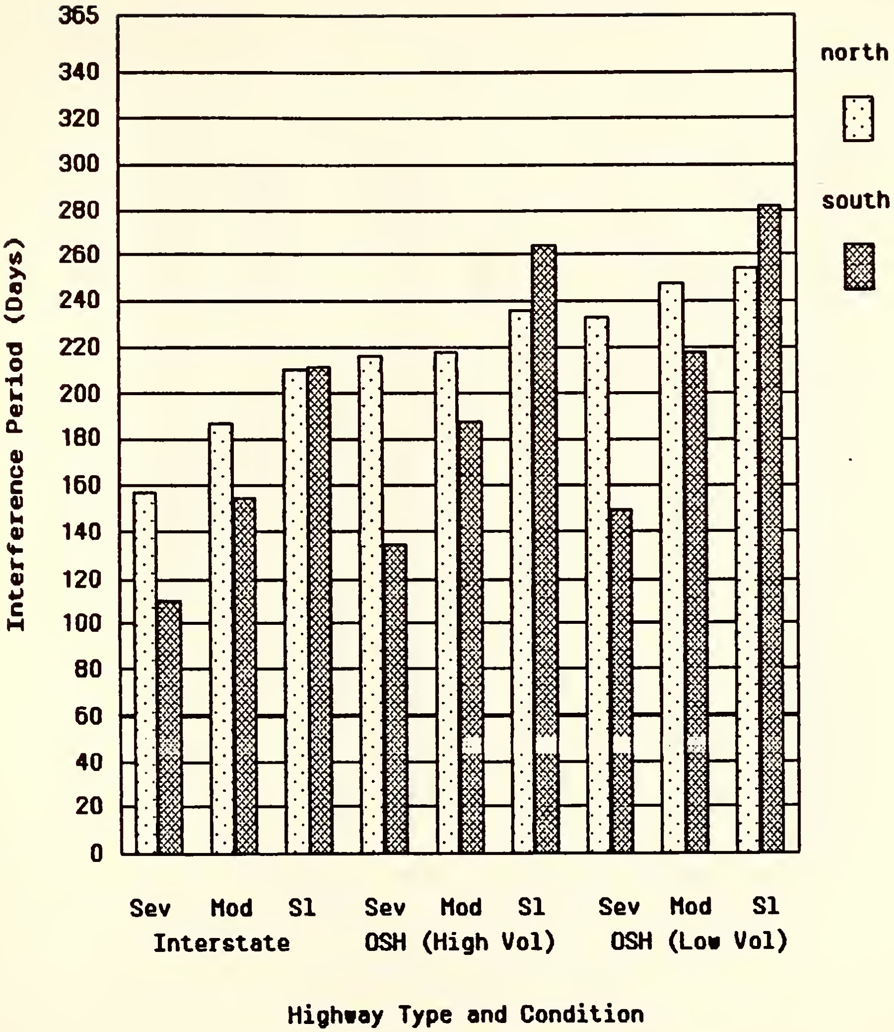

Figure B.3 Resurfacing Constraints for Premix Leveling (203).

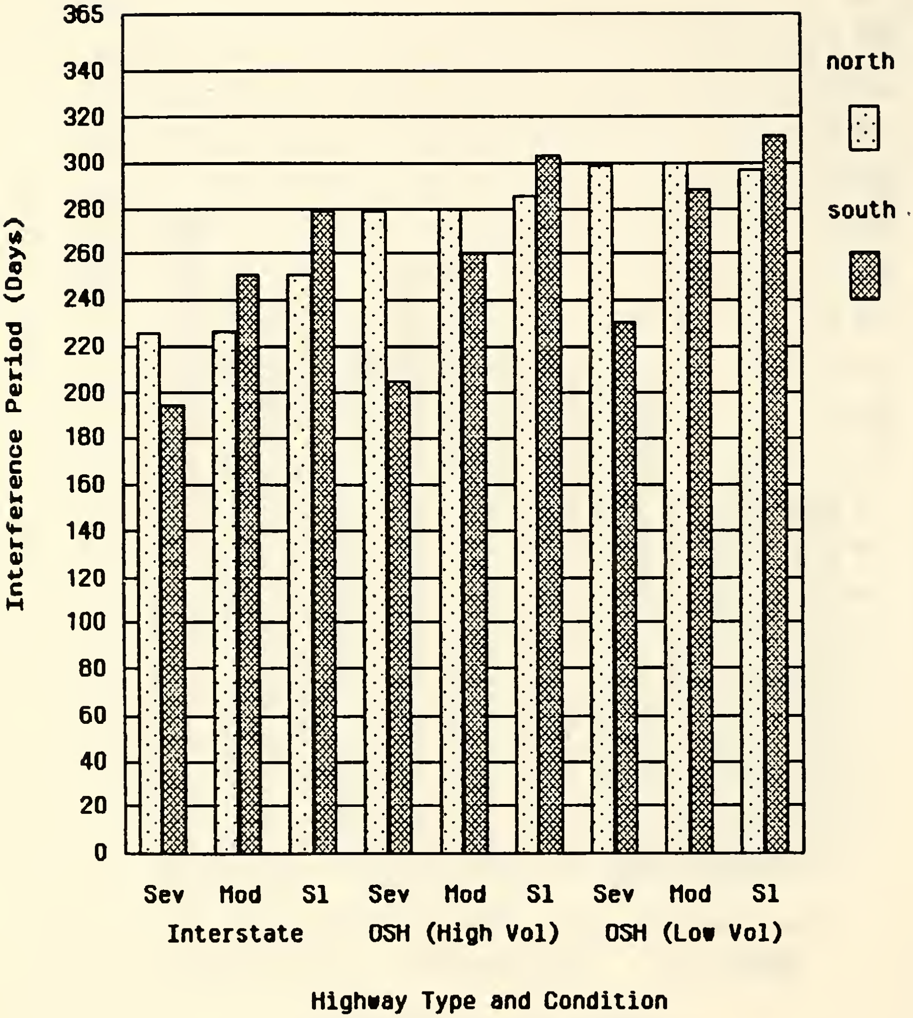

Figure B.4 Resurfacing Constraints for Full Width Shoulder Seal (204).

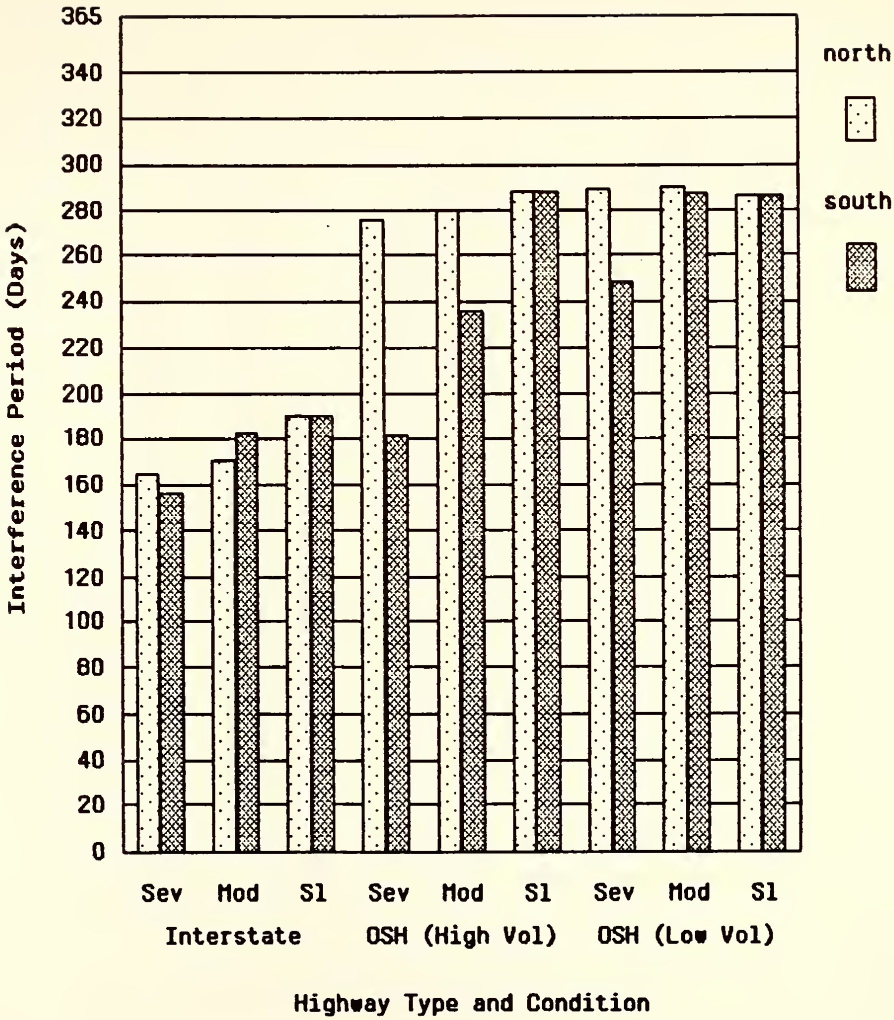

Figure B.5 Resurfacing Constraints for Chip Seal (205).

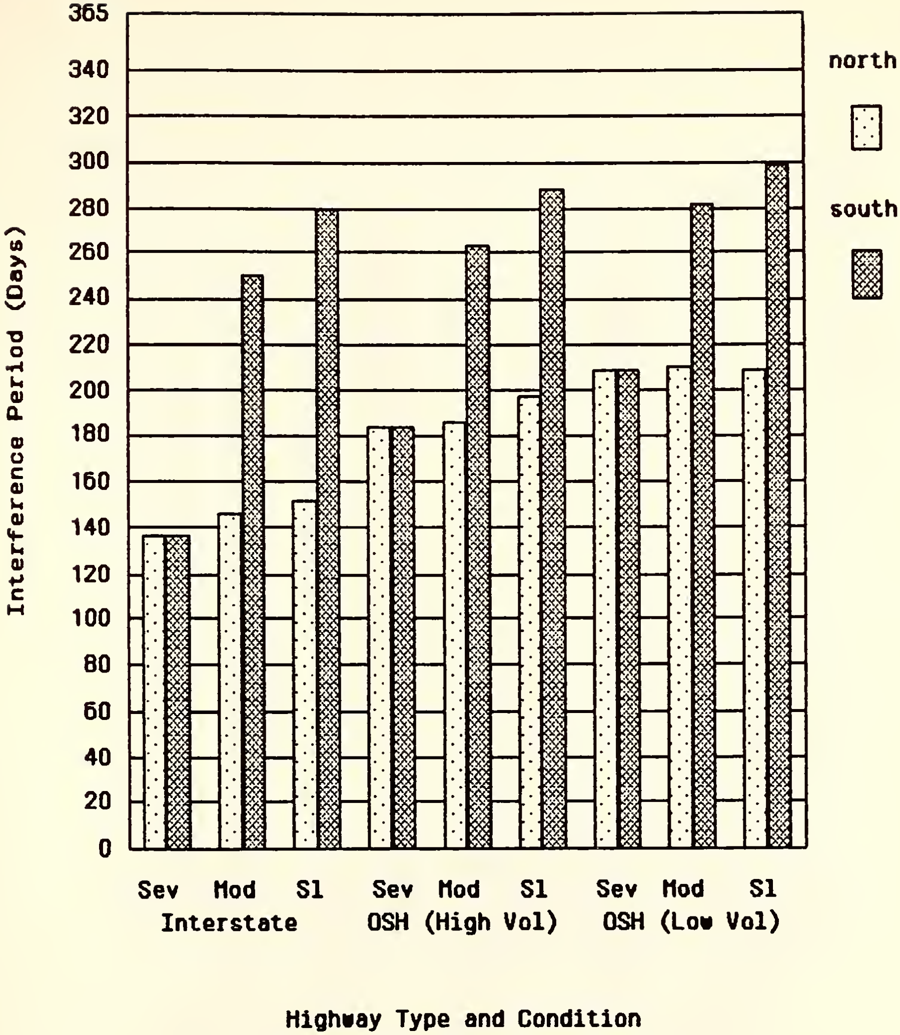

Figure B.6 Resurfacing Constraints for Sealing Longitudinal Cracks and Joints (206).

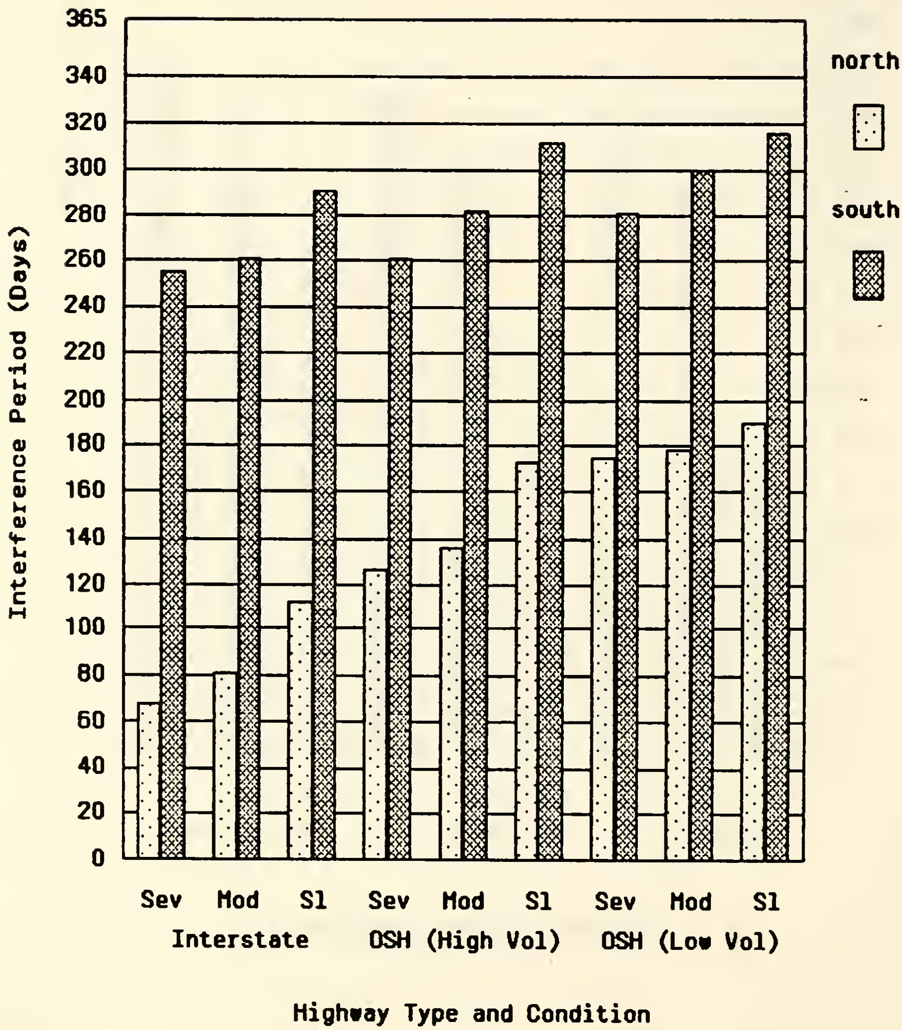

Figure B.7 Resurfacing Constraints for Crack Sealing (207).

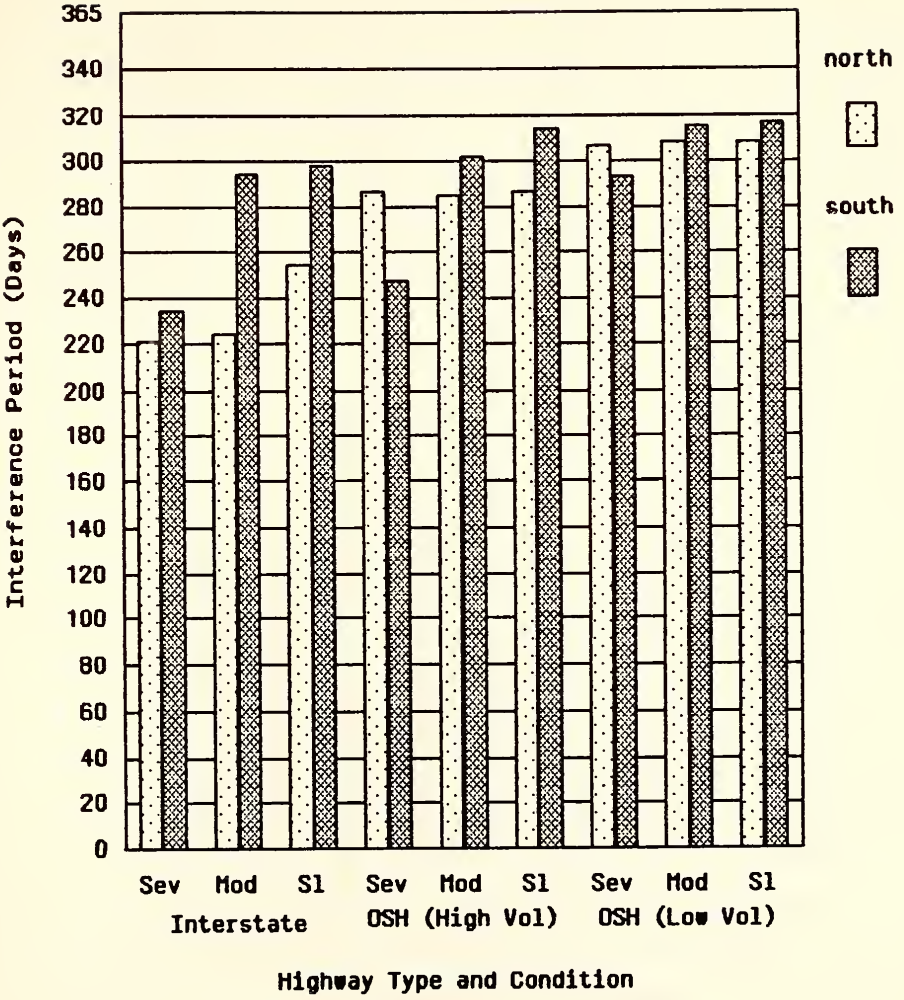

Figure B.8 Resurfacing Constraints for Sand Seal (208).

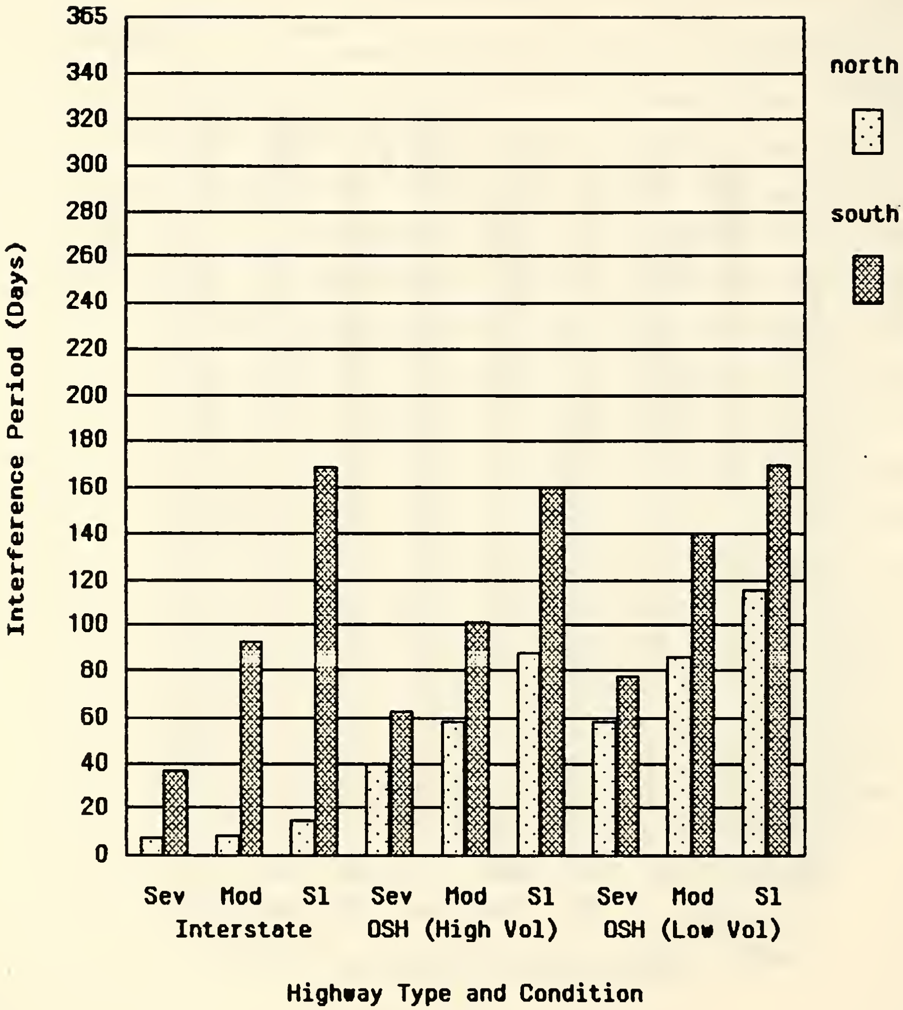

Figure B.9 Resurfacing Constraints for Spot Repair of Unpaved Shoulders (210).

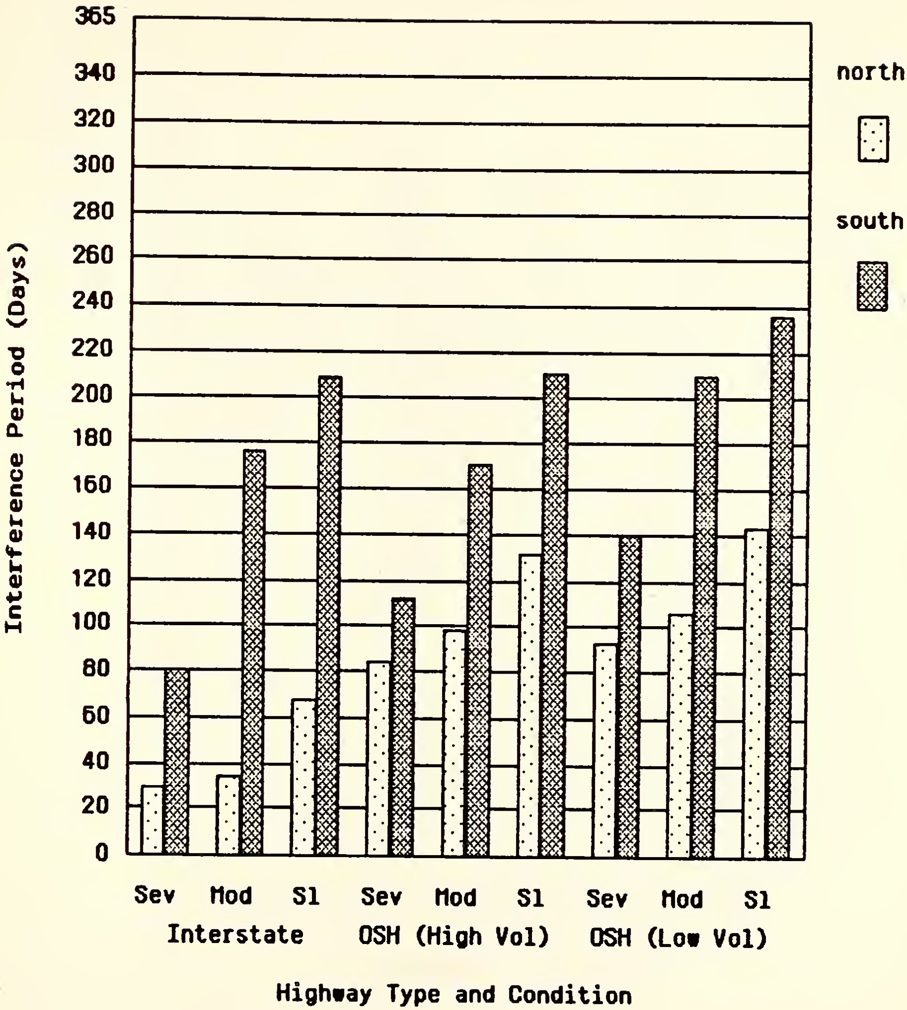

Figure B.10 Resurfacing Constraints for Blading of Unpaved Shoulders (211).

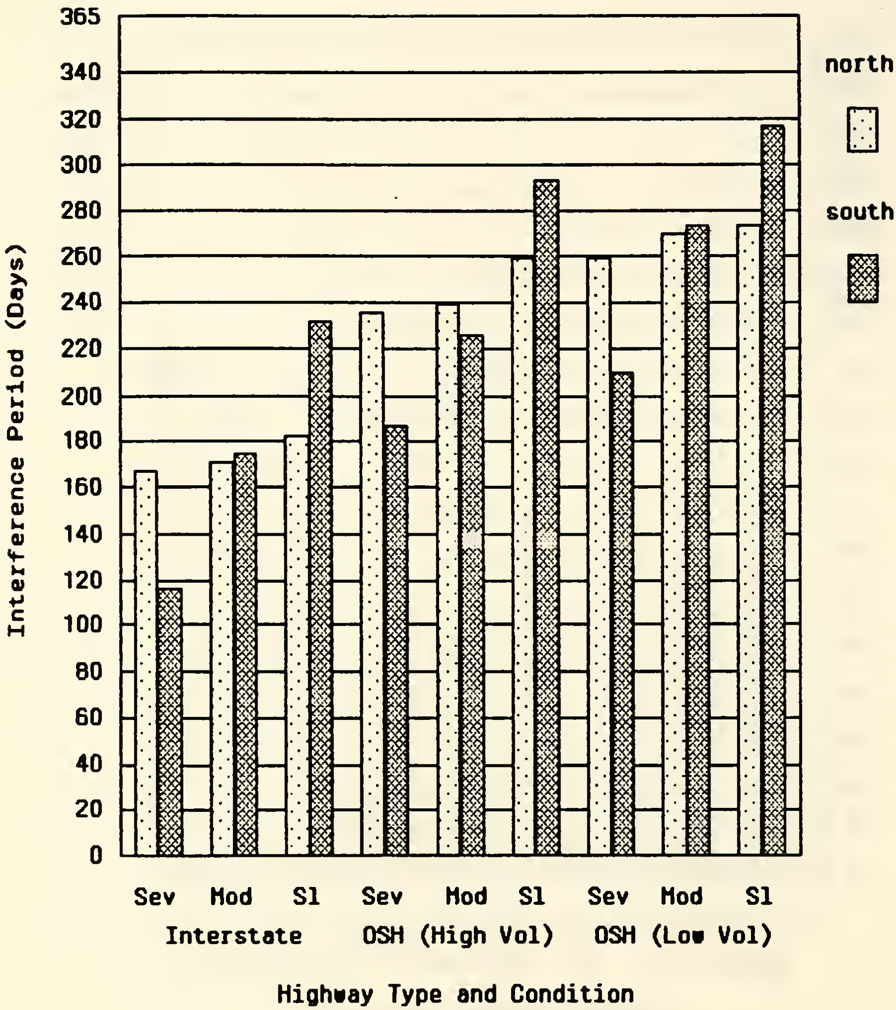

Figure B.11 Resurfacing Constraints for Clipping of Unpaved Shoulders (212).

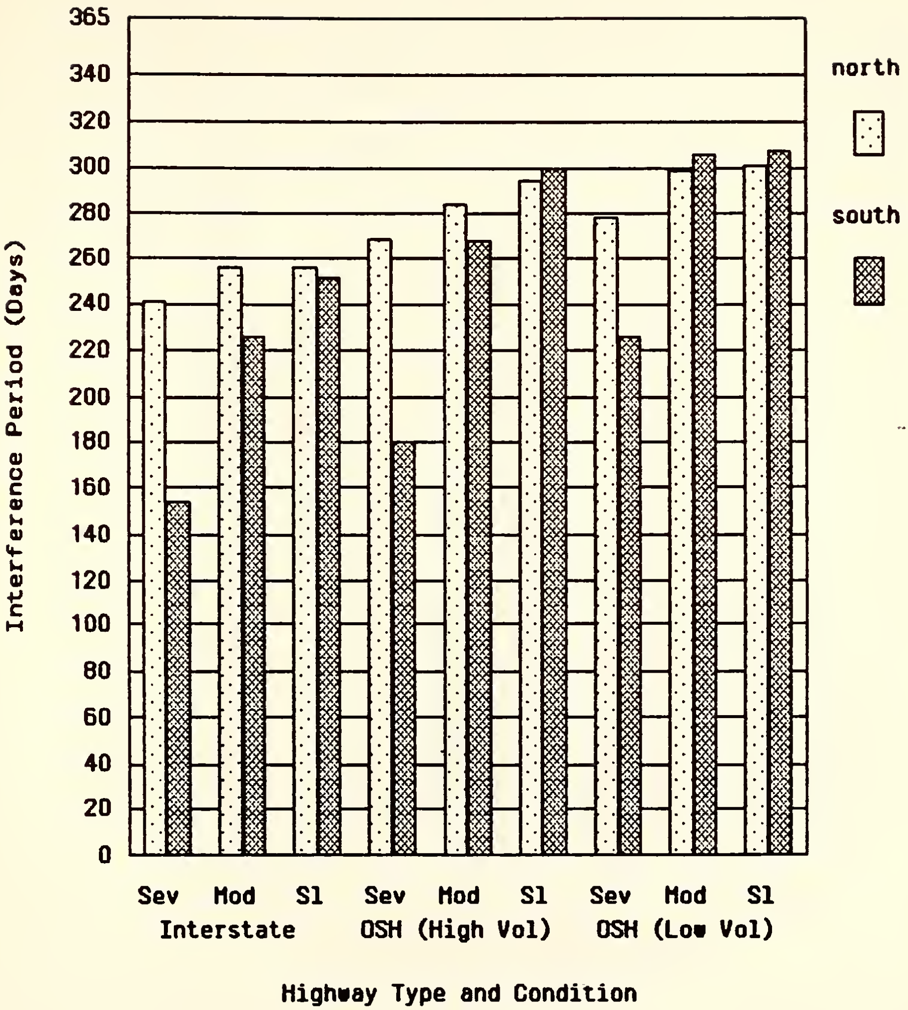

Figure B.12 Resurfacing Constraints for Reconditioning Unpaved Shoulders (213).

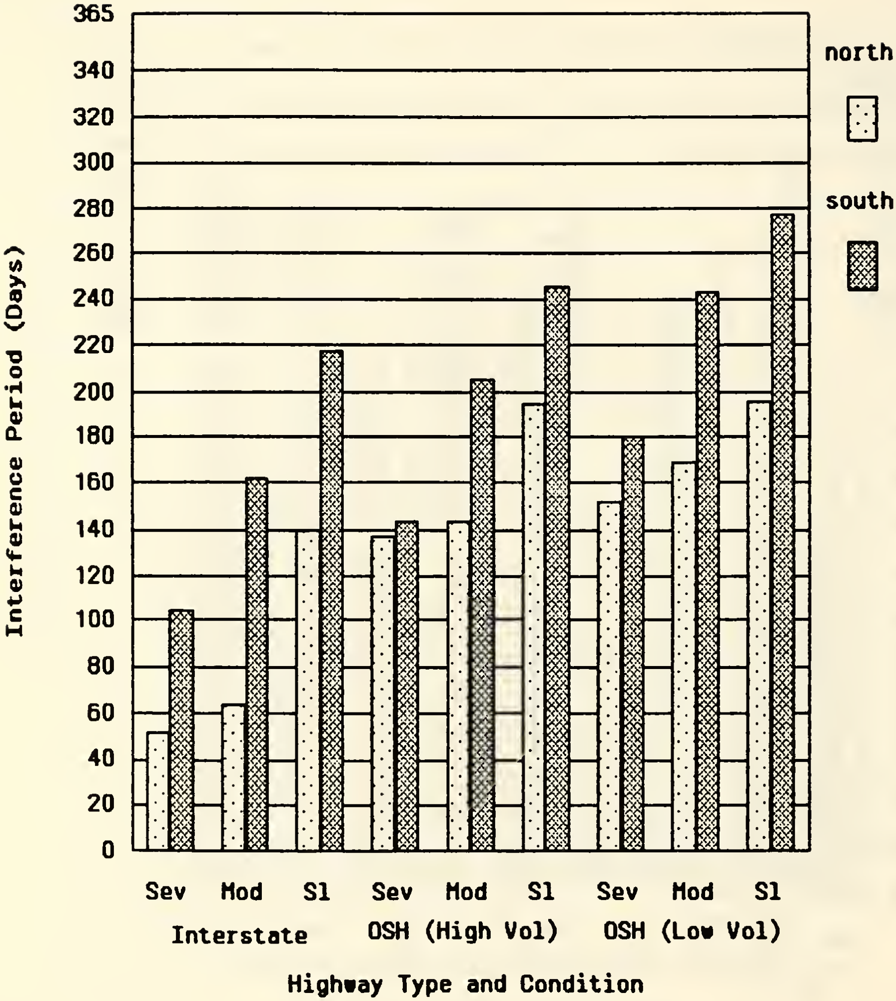

Figure B.13 Resurfacing Constraints for Clean and Reshape Ditches (231).

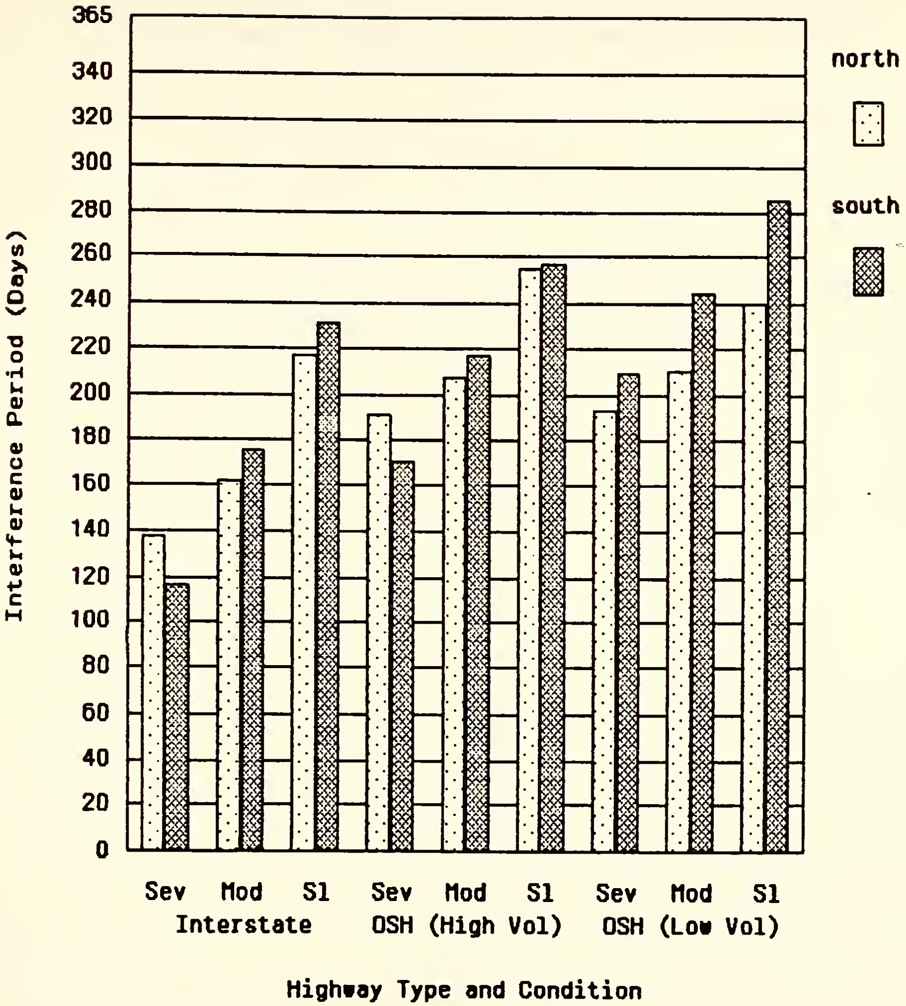

Figure B.14 Resurfacing Constraints for Motor Patrol Ditching (234).

APPENDIX C

COMPUTATION OF FINAL PRIORITY RATINGS FOR ROUTINE MAINTENANCE ACTIVITIES BY HIGHWAY CLASS AND DISTRESS SEVERITY LEVEL

The total number of routine maintenance activity-highway class distress severity level combinations in an optimization problem for routine maintenance programming is typically so large that it is practically impossible for one to assign realistically priority ratings simultaneously to all combinations. In the survey reported in this study, there was a total of 126 combinations. To overcome this problem, a partitioned two-stage rating procedure was devised to aid maintenance personnel in arriving at a set of priority ratings which reflects, as closely as possible, the relative priorities they have been intuitively applying in their daily work.

The nature of the partitioned survey, as depicted in Figure 2.2 of Chapter 2, makes it necessary to compute a final overall priority rating for each routine maintenance activity by highway class and distress severity level, by means of combining the partitioned priority scores in an appropriate manner. In selecting the procedure for computing the final priority ratings, the following two methods were considered:

(A) Multiplication Model

$$F_{ijk} = (f_2)_{ik} \times (f_1)_j \quad i=1,2,\ldots N_1,\ j=1,2,\ldots N_2,\ k=1,2,\ldots N_3 \qquad (C.1)$$

(B) Addition Model

$$F_{ijk} = w_2(f_2)_{ik} + w_1(f_1)_j \quad i=1,2,\ldots N_1,\ j=1,2,\ldots N_2,\ k=1,2,\ldots N_3 \qquad (C.2)$$

where,

F_{ijk} = priority rating for routine maintenance activity j of maintenance distress severity level k on highway class i

$(f_2)_{ik}$ = routine maintenance priority score for combination of highway class i and distress severity level k in relation to all other combinations of the two factors as obtained from stage II of Part 2 of the survey (See Figure 2.2)

$(f_1)_j$ = routine maintenance priority score for routine maintenance activity type j in relation to all other routine maintenance activity types as obtained from stage II of Part 1 of the survey (See Figure 2.2)

N_1 = total number of highway classes

N_2 = total number of routine maintenance activity types

N_3 = total number of distress severity levels

w_1 = numerical weighting factor

w_2 = numerical weighting factor

It is important to note that absolute values of individual priority ratings do not carry much physical meaning. It is their relative magnitudes in the entire set of priority rating scores that make the difference in an optimization programming analysis. It is, therefore, of interest to examine the ability of the two models in differentiating relative priorities of different combinations.

Consider two routine maintenance activity-highway class-distress severity level combinations, A and B. Let f_{a1} and f_{a2} be the priority scores of A from partitions 1 and 2 of the survey, respectively; and f_{b1}, f_{b2} the corresponding priority scores of B. For simplicity, take w_1=w_2 = 1. The following cases can be considered:

(a) $\min(f_{a1}, f_{a2}) > \max(f_{b1}, f_{b2}) \qquad f_{a1}, f_{a2}, f_{b1}, f_{b2} > 0$

Multiplication Model: $f_{a1} \times f_{a2} > f_{b1} \times f_{b2}$

Addition Model: $f_{a1} + f_{a2} > f_{b1} + f_{b2}$

Conclusion: Both models tally.

(b) $\max(f_{a1}, f_{a2}) < \min(f_{b1}, f_{b2}) \qquad f_{a1}, f_{a2}, f_{b1}, f_{b2} > 0$

Multiplication Model: $f_{a1} \times f_{a2} = f_{b1} \times f_{b2}$

Addition Model: $f_{a1} + f_{a2} = f_{b1} + f_{b2}$

Conclusion: Both models tally.

(c) $f_{a1} = f_{a2} = f_{b1} = f_{b2} \qquad f_{a1}, f_{a2}, f_{b1}, f_{b2} > 0$

Multiplication Model: $f_{a1} \times f_{a2} = f_{b1} \times f_{b2}$

Summation Model: $f_{a1} + f_{a2} = f_{b1} + f_{b2}$

Conclusion: Both models tally.

(d) $\max(f_{a1}, f_{a2}) > \max(f_{b1}, f_{b2}) > \min(f_{a1}, f_{a2}) > \min(f_{b1}, f_{b2})$

Multiplication Model: $f_{a1} \times f_{a2} = f_{b1} \times f_{b2}$

Addition Model: $f_{a1} + f_{a2} = f_{b1} + f_{b2}$

Conclusion: Both models tally.

(e) $\max(f_{b1},f_{b2}) > \max(f_{a1},f_{a2}) > \min(f_{b1},f_{b2}) > \min(f_{a1},f_{a2})$

Multiplication Model: $f_{a1} \times f_{a2} < f_{b1} \times f_{b2}$

Addition Model: $f_{a1} + f_{a2} < f_{b1} + f_{b2}$

Conclusion: Both models tally.

(f) $\max(f_{a1},f_{a2}) > \max(f_{b1},f_{b2}) > \min(f_{b1},f_{b2}) > \min(f_{a1},f_{a2})$

For easy explanation, the above expression is rewritten as follows:

$A1 > B1 > B2 > A2$

and $\Delta_1 = (A1 - B1) > 0$

$\Delta_2 = (B1 - B2) > 0$

$\Delta_3 = (B2 - A2) > 0$

the following conditions are possible:

(i) when $A1 + A2 < B1 + B2$, i.e. $\Delta_1 < \Delta_3$

we have $A1 \times A2 < B1 \times B2$

(ii) when $A1 + A2 = B1 + B2$, i.e. $\Delta_1 = \Delta_3 > 0$

we have $A1 \times A2 < B1 \times B2$

(iii) when $A1 + A2 > B1 + B2$, i.e. $\Delta_1 > \Delta_3$

we have $A1 \times A2 > B1 \times B2$ if $B_1(\Delta_1-\Delta_3) > \Delta_1(\Delta_2 + \Delta_3)$

$$A1 \times A2 < B1 \times B2 \quad \text{if} \quad B_1(\Delta_1 - \Delta_3) < \Delta_1(\Delta_2 + \Delta_3)$$

$$A1 \times A2 = B1 \times B2 \quad \text{if} \quad B_1(\Delta_1 - \Delta_3) = \Delta_1(\Delta_2 + \Delta_3)$$

Conclusion: The two models may give different orders of priority rating.

(g) $\max(f_{b1}, f_{b2}) > \max(f_{a1}, f_{a2}) > \min(f_{a1}, f_{a2}) > \min(f_{b1}, f_{b2})$

Analysis is similar to case (f).

Conclusion: The two models may give different orders of priority rating.

The analysis performed above shows that the models produce the same ranking of priority ratings for cases (a), (b), (c), (d) and (e), but discrepancies are found in cases (f) and (g). It can also be shown that the same conclusions will also hold for conditions where $w_1 \neq w_2$. This means that regardless of the computation method used, the top and the bottom portions of the final priority rating list are likely to stay unaffected. The discrepancies will lead to some differences in the ranking of priority ratings in the middle portion of the list.

In the context of the present study, the computation method selected is unlikely to affect the relative priority ratings of important maintenance activities on Interstate or high volume OSH with high distress severity level. Although differences in priority ratings may cause some changes in the resulted optimized program, the impact would be somewhat weakened by the presence of other constraints in the optimization process.

While the multiplication model is used in this study, one should not overlook the potential usefulness of the addition model. A highway agency may marginally influence the results in favor of certain policy preference through the use of the weighting factors w_1 and w_2. The values of w_1 and w_2, however, are not expected to be very different from the simple case of $w_1 = w_2$.

APPENDIX D

GUIDE TO USING THE PROPOSED OPTIMIZATION MODEL

This appendix provides a guide to potential users of the optimization model proposed in this report. A step-by-step instruction is given below for input preparation. The execution of the mathematical program is covered in the User's Guide in Reference 21 of the main report, users may make reference to it for details. The interpretation of a 'sample product' of the optimization analysis is also discussed.

Input Preparation

Step 1 — If priority ratings of routine maintenance activities by highway class and distress severity level are not already available, conduct a survey using the recommended procedure in this report to obtain a list of priority ratings. These priority ratings, symbolically represented by F_{ijk}, will set up the objective function given in Eq. (3.1). A sample product of F_{ijk} is found in Table 2.7 and Table 3.5.

Step 2 — If suspension periods of routine maintenance activities by highway class and distress severity level are not already available, conduct a survey using the recommended procedure in this report to obtain this information. A sample product of suspension period survey is found in Table 2.9. Next, apply Eqs. (2.1) and (2.2) to compute interference periods, d_{ijk}.

Step 3 — Determine the length of routine maintenance scheduling period and

compute the number of work-days, D, in this period. Steps 2 and 3 will completely define γ_{ijk} in Eq. (3.7). A sample of γ_{ijk} values is given in Table 3.6.

Step 4 — Perform a condition survey of pavement, shoulder and drainage elements for highways within the network concerned. The procedure for conducting the survey has been discussed in Reference 6. A sample product of this survey, as required for input to the optimization model, is as shown in Table D.1.

Table D.1 Condition Survey Data

Location of Highway Section	Highway Class	Distress Severity Level	Type of Maintenance Activity Needed	Amount of Work (Production Units)

Step 5 — Compute, on the basis of Step 4, the total amount of maintenance

needs (the last column of Table D.1) by activity type, highway class and distress severity level. The quantities represent directly the parameter $(\frac{T_{ijk}}{U_{ijk}})$ defined in Eq. (3.2). A sample of these quantities is given in Table 3.6. Steps 3, 4 and 5 thus set up Eq. (3.2) completely.

Step 6 — Obtain from performance standards (see Refs. [7] and [8] in main report) data on (i) daily production rate, U_{ijk} in Eq. (3.3), (ii) unit costs, C_{ijk} in Eq. (3.3), (iii) manpower requirements, h_j in Eq. (3.4), (iv) equipment requirements, q_{jr} in Eq. (3.5), and (v) material requirements, M_{js} in Eq. (3.6).

Step 7 — Determine available budget, B. Steps 6 and 7 set up Eq. (3.3) completely.

Step 8 — Determine manpower availability, H in Eq. (3.4). Steps 6 and 8 set up Eq. (3.4) completely.

Step 9 — Determine equipment availability, Q_r in Eq. (3.5). Steps 6 and 9 set up Eq. (3.5) completely.

Step 10 - Determine material availability, M_s in Eq. (3.6). Steps 6 and 10 set up Eq. (3.6) completely.

Step 11 - Present all equations set up in Steps 1 through 10 in format according to Reference 21 in the main report, and execute by means of an integer programming software.

Interpretation of Results

The output of the computer programming analysis to the problem set up in the preceding section is expressed in terms of the variables W_{ijk} in work-days, as shown in part (a) of Table 3.8. To use these results for programming and scheduling purpose, one merely needs to link them to the original condition survey data record as depicted in the sample form in Table D.1. One can therefore, work backward using Table D.1 to pick up the location of sections that have been selected to receive routine maintenance treatment for the maintenance period analyzed.

The results in terms of W_{ijk} can be used to carry out slack or surplus analysis on various resources. This analysis would indicate to the user what resources will be fully utilized during the maintenance period. Sensitivity analysis can also be performed to determine if it is worth increasing any of the resources necessary for the period analyzed.

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